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MOTOR FUELS *from* FARM PRODUCTS

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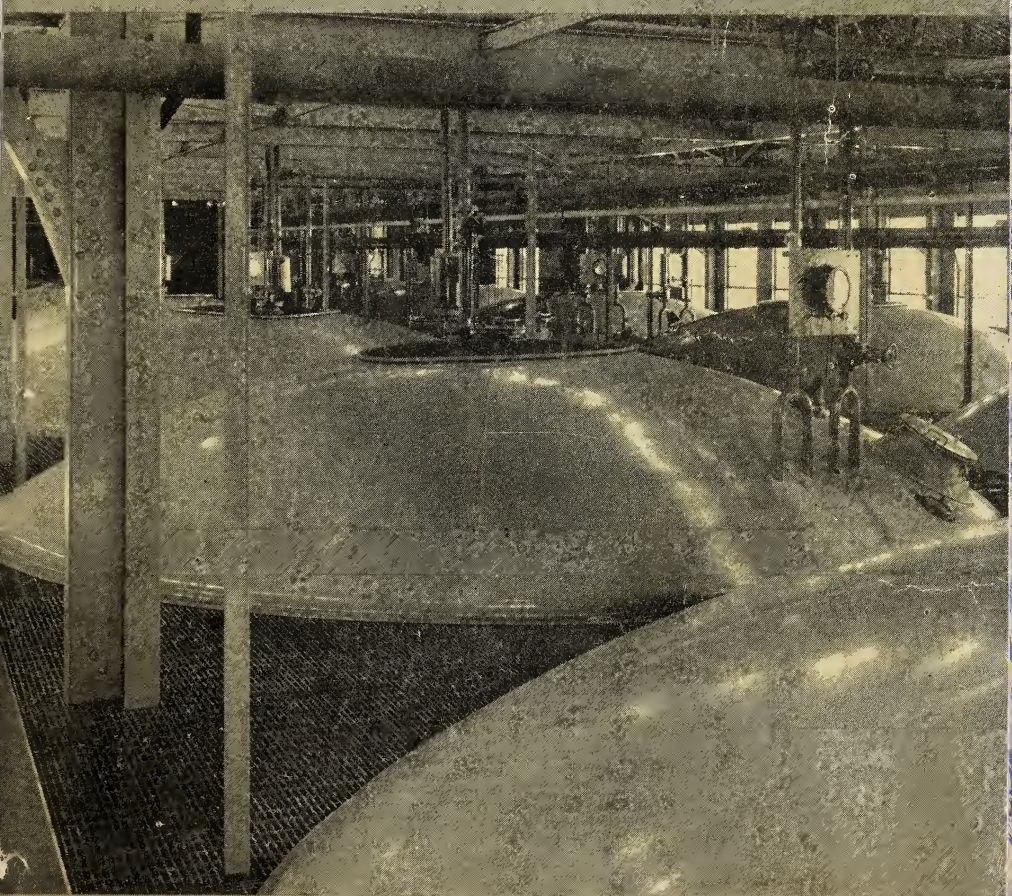

U.S. DEPARTMENT OF AGRICULTURE
MISCELLANEOUS PUBLICATION No. 327

UNITED STATES DEPARTMENT OF AGRICULTURE

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Washington, D. C. December 1938

MOTOR FUELS FROM FARM PRODUCTS

By P. Burke Jacobs, *senior chemist*, and Harry P. Newton, *associate chemist*, *Industrial Farm Products Research Division, Bureau of Chemistry and Soils* [1]

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INTRODUCTION

Because of the paramount importance of motor fuels in modern civilization, especially as war material, numerous efforts have been made in recent years to develop substitute motor fuels with which to supplement petroleum. The greatest activity in this movement has been in foreign countries whose natural petroleum resources are inadequate, especially for defense needs. Certain chemical compounds, such as ethyl alcohol,[2] can be used with comparative success

[1] Grateful acknowledgment is made to the following organizations and individuals, as well as to the personnel of the organizations listed, for courtesies and assistance in the preparation of this publication such as furnishing data or illustrative material, advice concerning the text, or the granting of permission for inspection visits to commercial plants. G. T. Reich, technical director, Pennsylvania Alcohol Co., Leo M. Christensen, technical director, Atchison Agrol Co.; Arnold Daum, secretary, motor fuels committee, American Petroleum Institute; F. M. Shipman, technical director, the Brown-Forman Distillery Co.; Samuel Fisher, treasurer, the Acme Coppersmithing & Machine Co.; C. S. Boruff, technical director, Hiram Walker & Sons, Inc.; E. C. Boeckler, the Lummus Co.; the Calvert Distilling Co.; the Commercial Solvents Corporation; the United States Industrial Alcohol Corporation; the Louisville Drying Machinery Co.; the Merrimac Chemical Co. (alcohol division); the Vulcan Copper & Supply Co.; the E. B. Badger & Sons Co.; O. C. Bridgeman, National Bureau of Standards; H. Wollner, U. S. Treasury Department; E. C. Sherrard, Forest Service; A. C. Fieldner and associates, U. S. Bureau of Mines; U. S. Bureau of Agricultural Economics, Plant Industry, and Animal Industry.

The alcohol plant photographs were furnished by Hiram Walker & Sons, Inc., the Acme Coppersmithing & Machine Co., and the Lummus Co. It is regretted that it was not possible to include all the illustrative matter generously furnished by these and other firms.

[2] In general, since ethyl alcohol is the material now most commonly understood by the term "motor-fuel alcohol" and since this alcohol is apparently produced the most cheaply of all the possible alcohols or other compounds, the data here are expressed in terms of ethyl alcohol.

Motor-fuel alcohol is commonly referred to as power alcohol. Other variants of this term are "fuel alcohol," "alky-gas," "agrifuel," "agricrude alcohol," "agrol," "blended alcohol," "alcohol fuel," and "farm gasoline."

as fuel in the modern type of internal-combustion engine. Since these may usually be produced by chemical or bacteriological processes from saccharine, starchy, or cellulosic vegetable materials, much of the experimentation for the production of substitute motor fuels has been directed toward the use of agricultural products as raw material. In many cases this activity has been interrelated with a national agricultural program. This foreign experimentation with agricultural materials has naturally aroused great interest in the United States.[3] It must be remembered, however, that the situation in this country is not directly comparable with that in foreign countries.

The United States originally had a large part of the world's supply of petroleum, and at present there is no shortage of petroleum fuel in this country. However, disturbed agricultural conditions have been experienced, with great variations in the income from farm products, due to overproduction in good years and underproduction in bad years, fluctuating demand, and other factors. Various governmental measures have been adopted to cope with this problem, which in recent years have included crop-raising restrictions to avoid recurrence of surpluses. Besides crop surpluses, however, great quantities of unmarketable culls and wastes are produced, as well as quantities of relatively perishable crops which by reason of geographical location or temporarily glutted markets cannot be sold before they deteriorate. All these constitute an important part of the problem of adequate farm income. In addition, the various crops are separated commercially into several standard grades according to quality, and there may be difficulty in disposing of the poorer grades.

Some continuously available form of industrial utilization should be found for the unsalable material usually produced in excess of direct food or feed market requirements in normal production years. With some crops this is accomplished to some degree by the manufacture of derived products for food purposes, such as cornstarch or sirup from corn and starch from potatoes, the quantities so used annually depending somewhat on price and market conditions. More recently the chemical utilization of agricultural raw materials has begun, as for example, the production of lactic acid and lacquer solvents from corn or furfural from oat hulls. Such chemical markets, however, are usually limited. In addition to culls and surpluses, vast quantities of byproduct cellulosic materials, such as cornstalks, straws, sugarcane bagasse, corncobs, hulls, and shells, which now are largely wasted each year, might serve as raw materials for industrial purposes.

Attempts to control or stabilize agricultural prices by maintenance of a fairly constant carry-over stock would necessitate either a restriction of subsequent crops or a means of economically utilizing or disposing of any additional surplus over the normal supply in such manner that food or feed prices would not be adversely affected.

Because of the vast quantities of motor fuel now required annually for the operation of automobiles, tractors, and other mechanized forms of power in the United States, it seems logical to consider agricultural products or surpluses as a partial source of supply. Although there is

[3] In 1933 the U. S. Department of Agriculture issued a report (*74*)[4] which covered some of the same ground as this report but dealt more particularly with economic phases of the problem, summarizing other aspects. The background for that report was the economic situation obtaining at that time. The present study represents an independent survey based more largely on the technical and agricultural aspects of the subject. The information in the previous publication serves as a background for the data presented here.

[4] Italic numbers in parentheses refer to Literature Cited, p. 125.

no shortage of petroleum fuel at present, petroleum deposits are irreplaceable, and at present rates of consumption cannot last forever. Conservation of our present supply, therefore, should be attempted. In any discussion of conservation of natural resources, it must be remembered that agriculture as frequently practiced is, after all, a form of mining whereby certain constituents of the soil are depleted. Since, however, depleted soil can be restored by proper agricultural practices and adequate restoration of the lost components, it would seem that the utilization of soil, air, water, and sunshine, in the form of carbohydrate crops, as a source of motor fuel would merit consideration on the basis of the present agricultural and economic situations and the necessity for conserving petroleum resources.

The chemical feasibility of producing motor fuel from agricultural products has long been established, but the economics of price are not yet in satisfactory adjustment, although it will probably be only a short time before necessary increases in the price of petroleum will tend to equalize the present cost differential between petroleum and fuels from agricultural sources. However, it should be kept in mind that it may be possible to produce suitable replacement fuels from sources such as coal, shale oil (both of which, however, also are irreplaceable), waste sulphite liquors, and wood, and by synthesis from gases, at prices comparable with those of fuels from agricultural sources. Any replacement fuels must, of course, be of such character as to be immediately adapted for use with present automotive equipment, but a mutual adjustment between the engine and any fuel would probably be made eventually.

A motor-fuel alcohol program should have a source of raw material that will be adequate for many years. Since alcohol does not usually deteriorate from long standing and since it represents a concentration of bulk from the original raw material, it may be possible to some extent to reduce large crop surpluses to the form of alcohol for storage against a subsequent year of shortage, provided the storage charges and tie up of capital thus incurred do not involve an eventual loss. In a poor crop year the capital charges on the alcohol plants would have to be met, however, even if these plants were inactive, and to protect the plant organization the trained personnel of such plants would have to be carried over the inactive periods.

Recently some consideration has been given to the possibility of growing "industrial" crops, crops grown directly for industrial use. Such crops would perhaps net a lower unit price return but would permit farm overhead to be distributed over more production units. Any such agricultural development, however, would be necessarily limited by the possible market for the chemical or industrial products made from such crops. Agricultural materials should not be substituted in industry at the expense of raw materials now used, nor should such substitution disturb present operations unduly. Under present conditions, and especially in the absence of wartime conditions, the only adequate outlet for great quantities of agricultural materials seems to lie in the field of motor fuel, since the market is sufficiently large to absorb the new products without too great disturbance in the existing situation. Such use of alcohol would defer the date of exhaustion of the petroleum reserves, and this might be an actual benefit to the petroleum industry, since the life of the industry would be extended.

To evaluate the economic possibility of making motor fuel from agricultural products, it is necessary to know first the amount of suitable raw material that is now available or could probably be made available later. The possibility of increasing acre yields and decreasing crop-raising costs should be studied. The distribution of the crops and the problems of harvesting, collecting, transporting, and storing without serious deterioration should be considered, especially in the case of perishable materials. Technical problems of processing the materials and refining the products would have to be solved. The net price that could be paid for the raw material, its value in comparison with other available raw materials, the cost of producing the alcohol, and the selling price such a product could command on the basis of comparative efficiency as motor fuel are essential factors in the undertaking and should be looked at realistically.

In addition, the production of motor fuel from agricultural products would present social, legal, and economic aspects, and their various interrelationships should be carefully considered. Above all, it must be remembered that the situation is continually changing and that consideration of the problem should include future as well as present conditions.

AGRICULTURAL ASPECTS

The feasibility of producing motor fuel from agricultural products largely depends on the availability of suitable raw materials. A study of present United States crops is presented in the following pages.

CROP DISTRIBUTION

The producing areas for certain crops and approximate crop concentrations of the various areas are shown graphically in figures 1 to 18, which were prepared by the United States Bureau of Agricultural Economics.

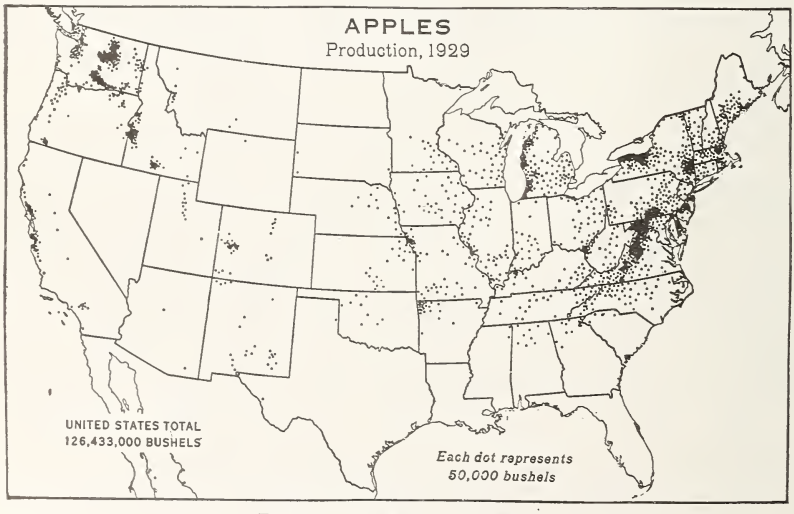


FIGURE 1.—Location of apple crop.

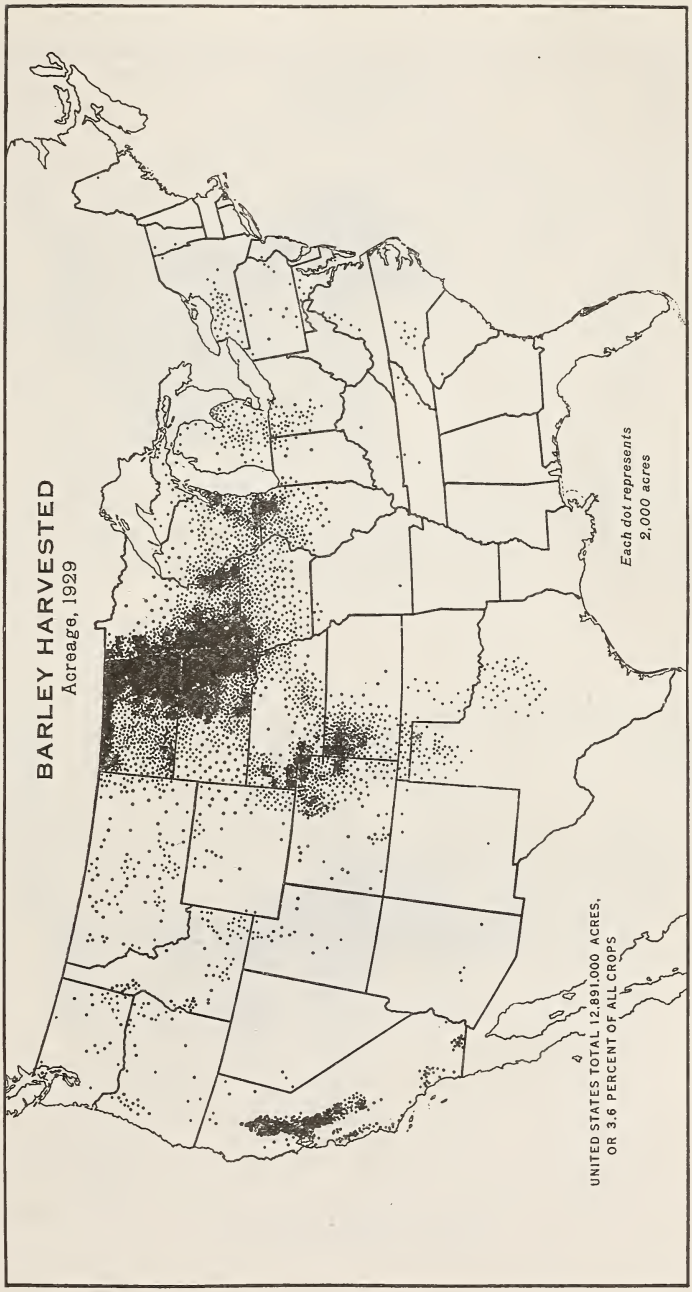


FIGURE 2.—Location of area producing barley.

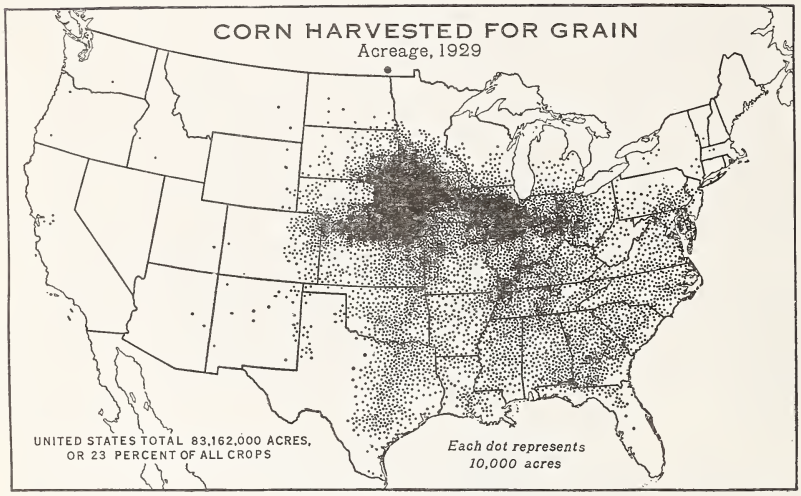


FIGURE 3.—Location of area producing corn.

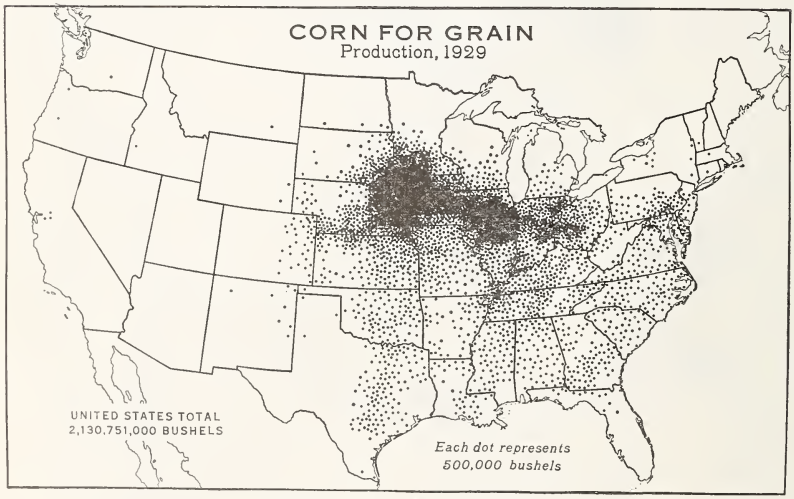


FIGURE 4.—Location of corn crop.

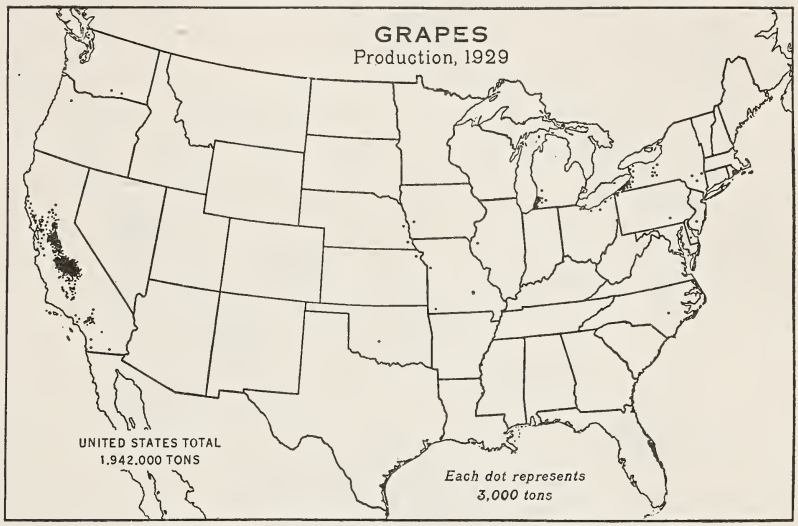


FIGURE 5.—Location of grape crop.

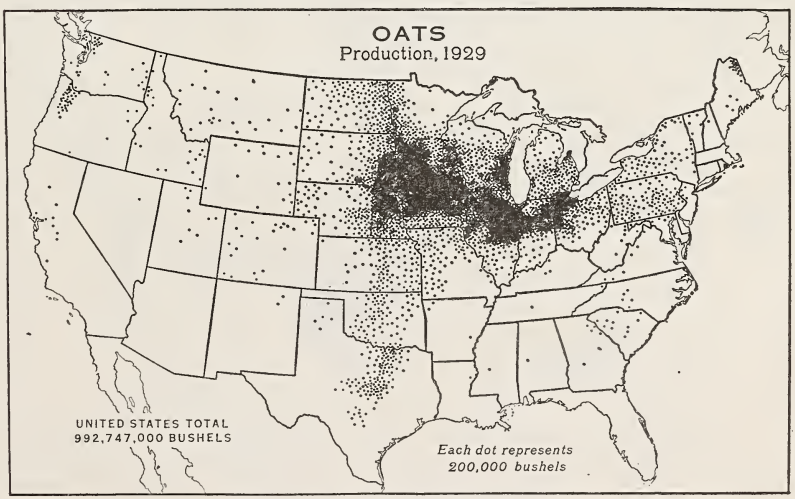


FIGURE 6.—Location of oat crop.

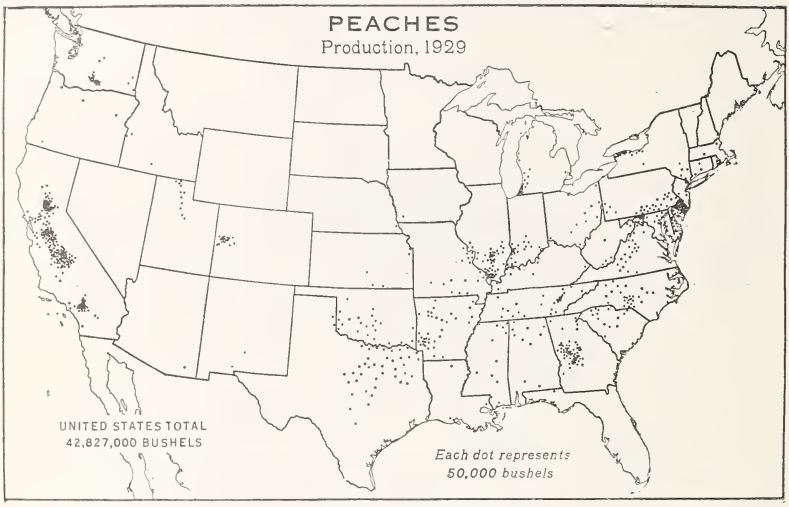


FIGURE 7.—Location of peach crop.

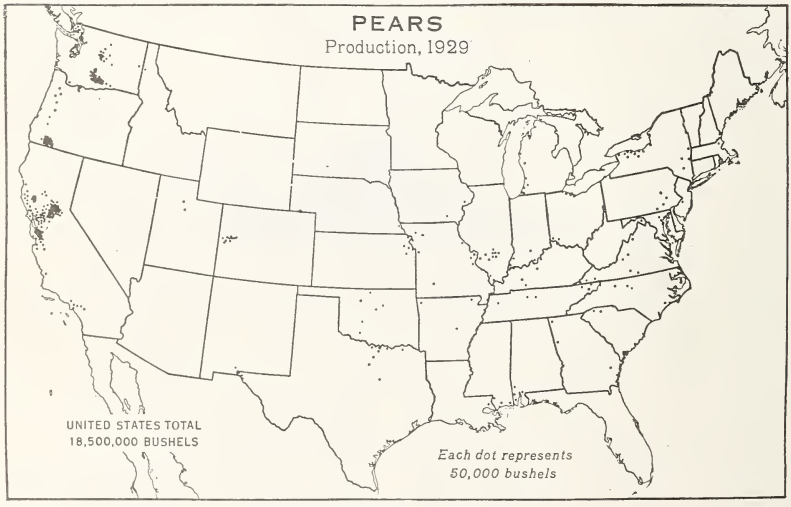


FIGURE 8.—Location of pear crop.

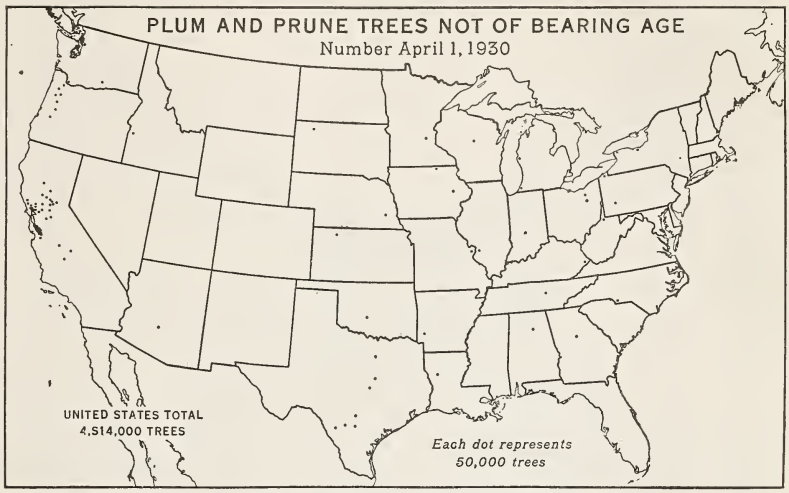


FIGURE 9.—Location of plum and prune crop.

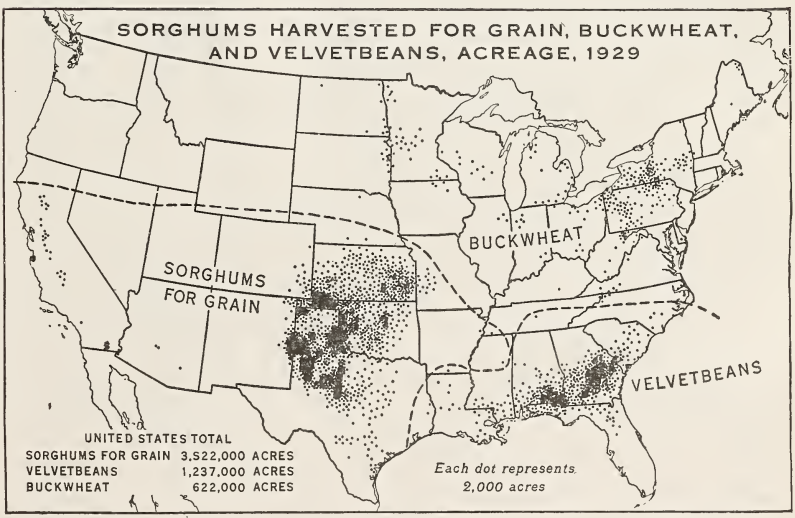


FIGURE 10.—Location of areas producing sorghums, buckwheat, and velvetbeans.

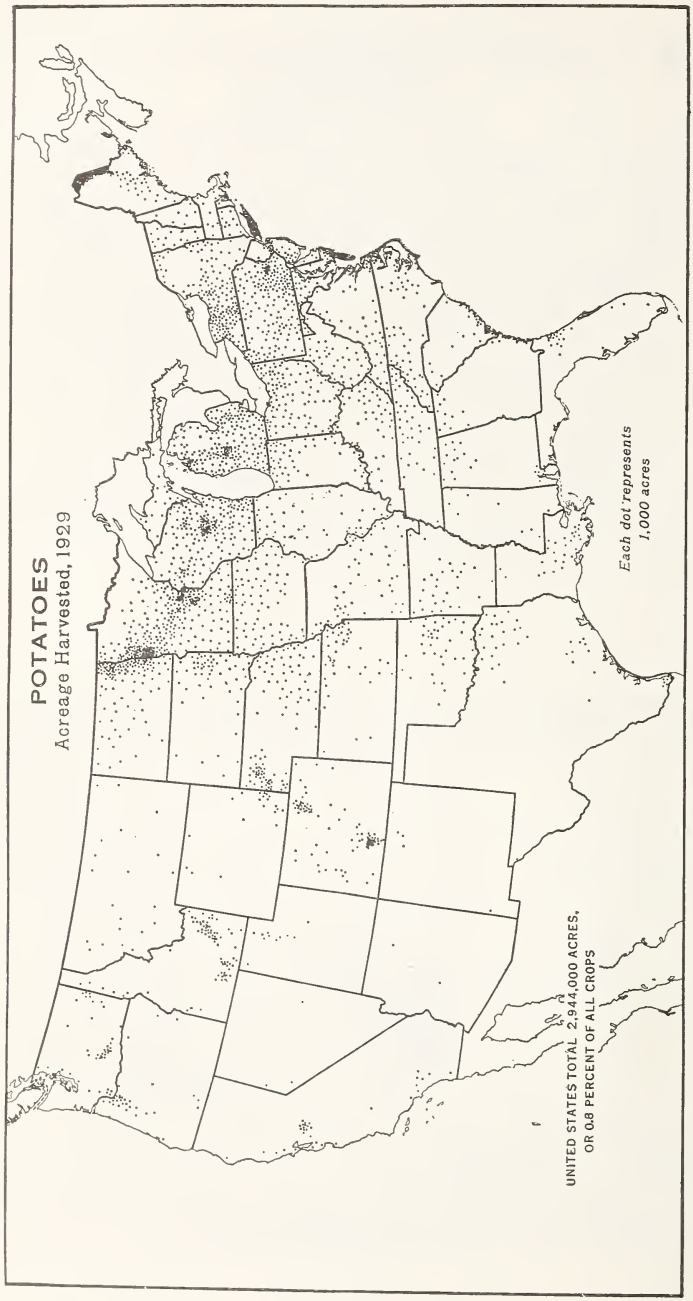

POTATOES
Acreage Harvested, 1929
Each dot represents 1,000 acres
UNITED STATES TOTAL 2,944,000 ACRES, OR 0.8 PERCENT OF ALL CROPS

FIGURE 11.—Location of area producing potatoes.

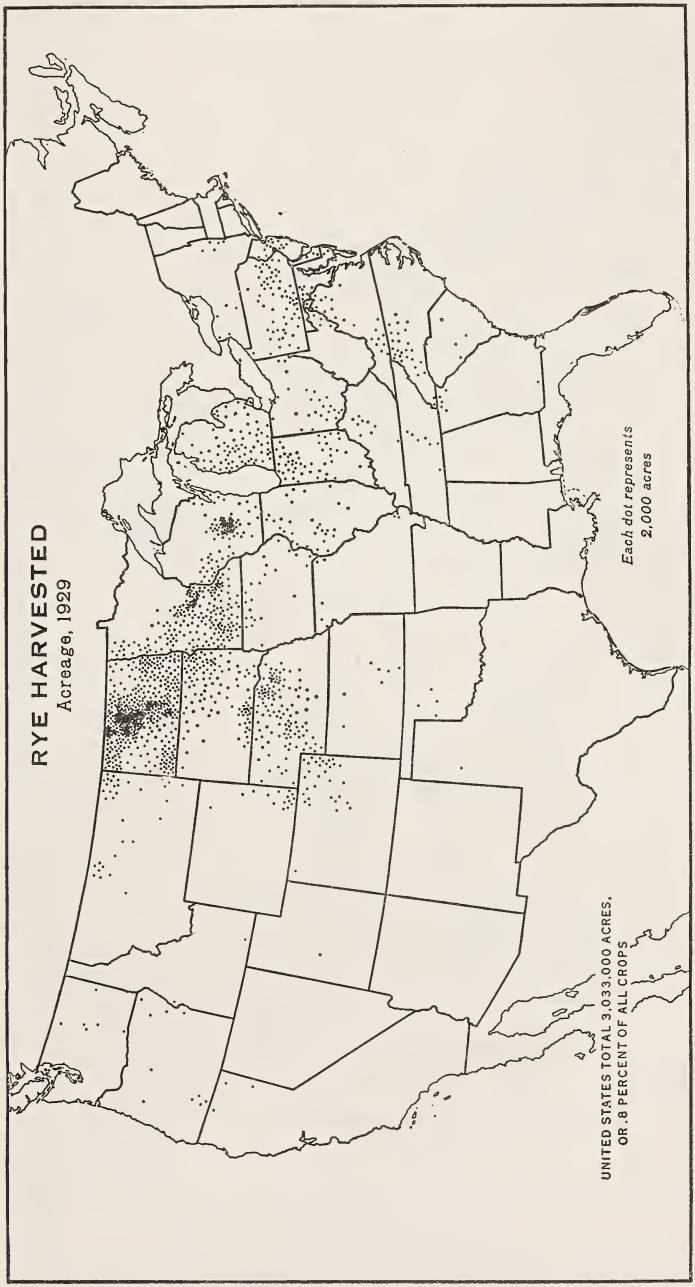


FIGURE 12.—Location of area producing rye.

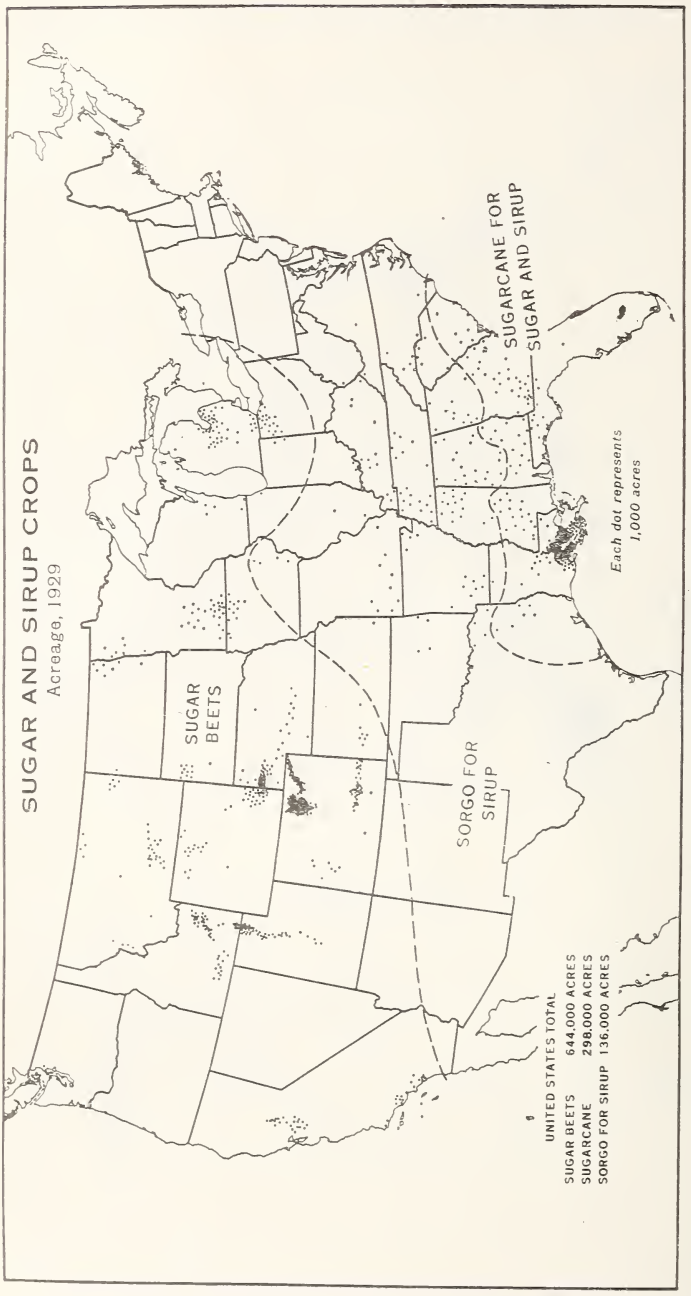


FIGURE 13.—Location of areas producing sugar beets and sugarcane.

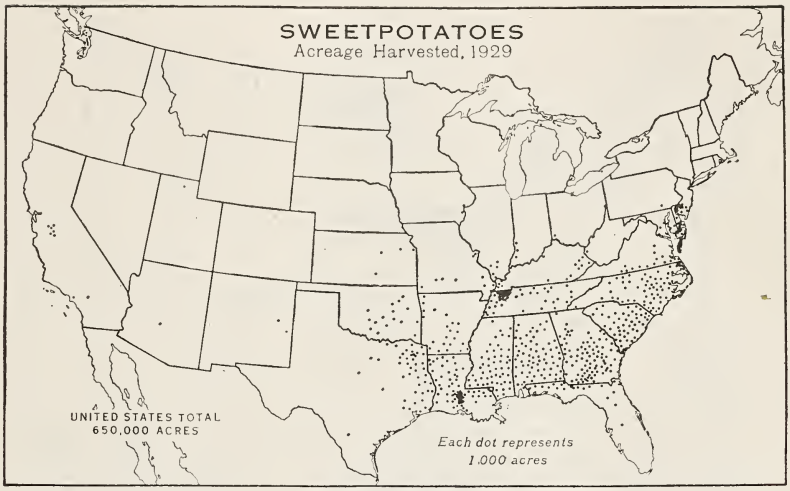


FIGURE 14.—Location of area producing sweetpotatoes.

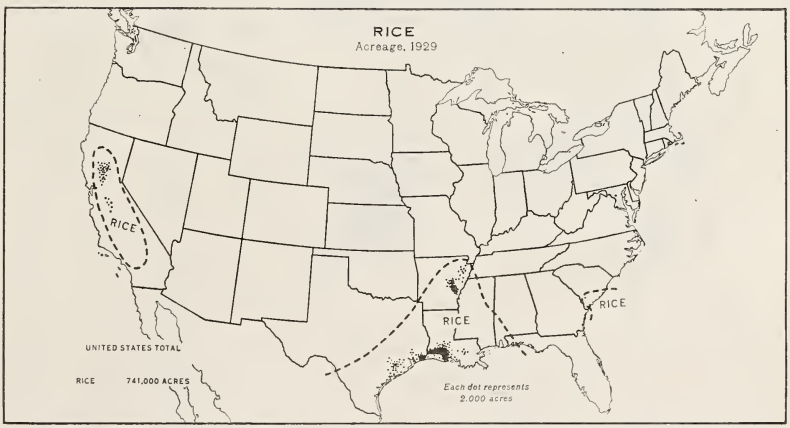


FIGURE 15.—Location of area producing rice.

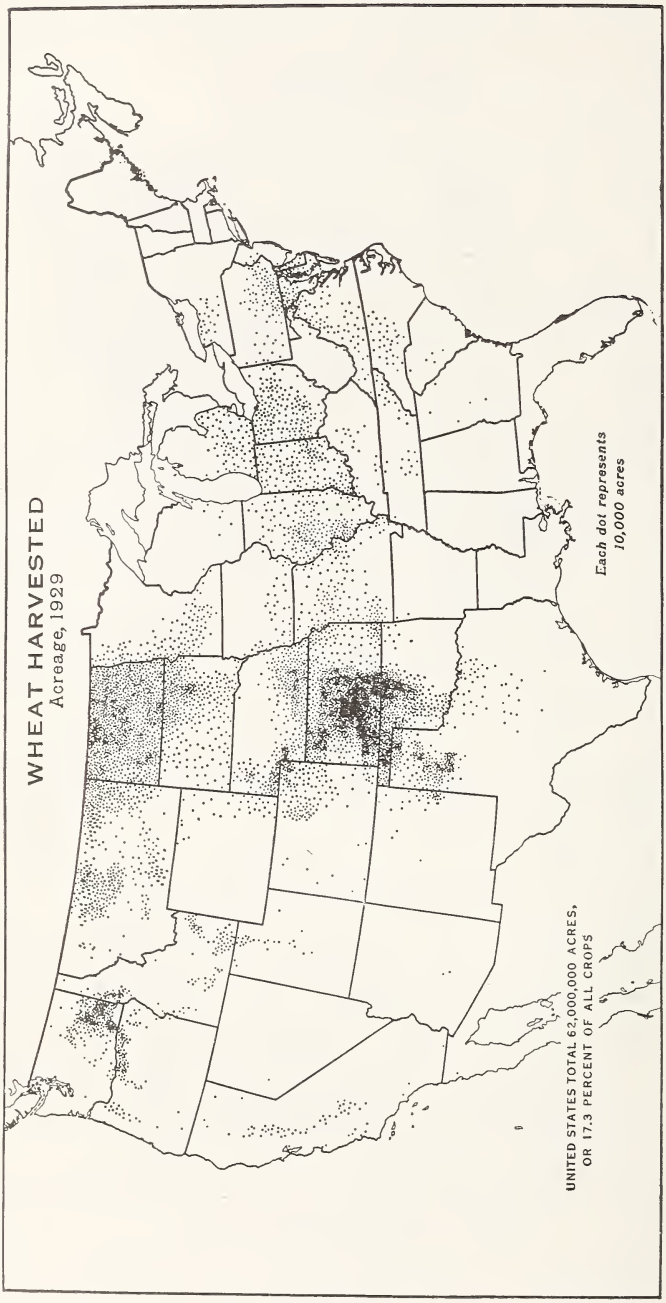


FIGURE 16.—Location of area producing wheat.

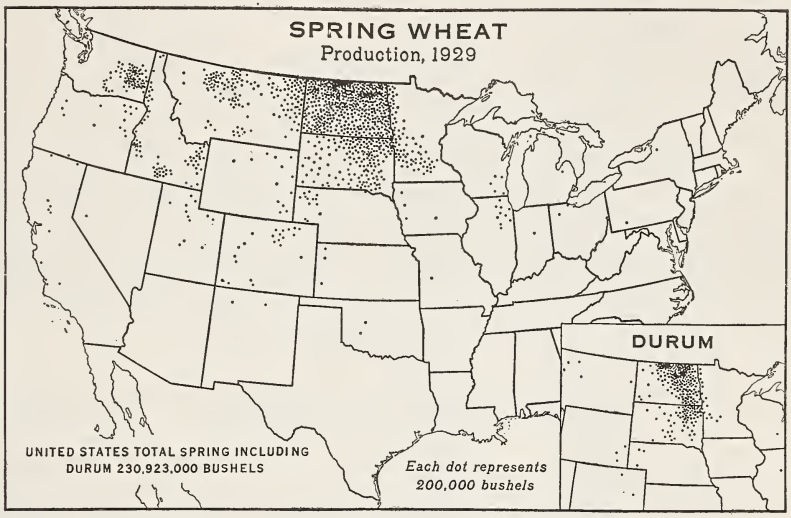


FIGURE 17.—Location of spring and durum wheat crops.

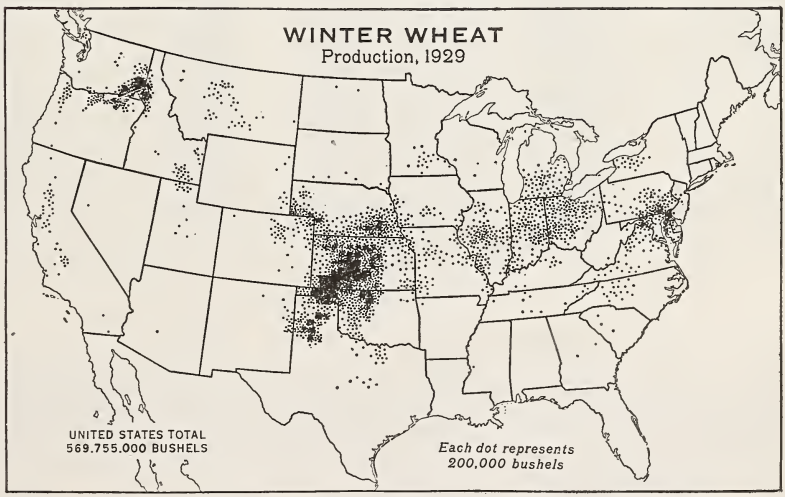


FIGURE 18.—Location of winter wheat crop.

CROP PRODUCTION[5]

Table 1 shows the production of possible alcohol raw materials for each State and for the entire United States (*73, 76*). The average crop production for a 5-year period (1928–32) and also the production figures for 1936 are shown in descending order for all States where the production exceeded an arbitrary minimum. A 10-year average yield per acre is given for some crops. The 10-year average percentage that was of marketable quality is shown for each crop for which figures were obtainable, both for each important State and for the United States (*77*). By inference, the remainder consisted of culls or miscellaneous low-grade materials, probably representing farm consumption, and in view of the present agricultural program and the need for utilization of unmarketable material it is in this portion that a considerable part of the raw materials for motor-fuel alcohol production might be expected to be found. At the same time some of the marketable percentage consisted of lower or sample grades, which might also become available for this purpose.

TABLE 1.—*Production of possible alcohol raw materials in the principal producing States and in the entire United States*

APPLES

State or Territory	Produced in—		Average yield per acre, 1923–32	10-year average percentage that was of marketable quality
	1928–32 (average)	1936		
	Bushels	*Bushels*	*Bushels*	
Washington	33,510,000	27,520,000		84
New York	19,012,000	10,200,000		75
Virginia	13,160,000	7,750,000		75
California	10,156,000	8,946,000		86
Pennsylvania	9,584,000	7,072,000		77
West Virginia	6,947,000	3,520,000		77
Michigan	6,641,000	6,864,000		76
Ohio	6,538,000	2,660,000		76
Idaho	5,066,000	3,102,000		83
Oregon	5,082,000	4,368,000		86
Illinois	4,545,000	1,696,000		72
North Carolina	3,411,000	2,590,000		71
New Jersey	3,295,000	2,850,000		81
Missouri	2,434,000	649,000		71
Total for United States	161,333,000	108,031,000		78.9

APRICOTS

	Tons	*Tons*	*Tons*	
California	227,400	223,000		

[5] The crop statistics presented here were prepared in 1936, at the beginning of this study, and represented the latest statistical information then available. Subsequent to that date the method of crop calculation used in the Agricultural Statistics of the United States Department of Agriculture, the source of information for this report, was somewhat changed. Since the revised figures differ only slightly and since the averages for the periods used (1928 to 1932 or 1922 to 1932) do not differ essentially from a similar average of later years, the figures have not been revised. The production variation of any crop from year to year may exceed the difference of such averages.

Crop estimates dealing with production, acre yields, etc., as well as the factors given for fermentable content, as mentioned hereafter in this text, are based on the crop situation as it now exists. The effects of variety and environment and their interrelations on the value of agricultural crops for industrial purposes have not been taken into account in this presentation except incidentally. Obviously, with many crops, changing the characteristics of the plants and selection and development of adapted forms would change the figures in the tables on sources of alcohol.

TABLE 1.—*Production of possible alcohol raw materials in the principal producing States and in the entire United States*—Continued

BARLEY

State or Territory	Produced in—		Average yield per acre, 1923–32	10-year average percentage that was of marketable quality
	1928–32 (average)	1936		
	Bushels	*Bushels*	*Bushels*	
Minnesota	49,615,000	31,620,000	25.2	86
North Dakota	39,055,000	4,522,000	17.6	82
South Dakota	35,277,000	8,977,000	19.6	86
California	29,594,000	29,925,000	26.5	88
Wisconsin	22,178,000	17,896,000	30.3	88
Iowa	17,882,000	7,056,000	28.8	89
Nebraska	15,386,000	5,520,000	21.4	86
Illinois	11,707,000	2,700,000	29.7	88
Total for United States	281,237,000	147,452,000	22.6	87.2

BUCKWHEAT

	Bushels	*Bushels*	*Bushels*	
New York	2,692,000	2,016,000	17.1	
Pennsylvania	2,576,000	2,418,000	17.4	
Minnesota	479,000	100,000	10.6	
Ohio	410,000	320,000	17.1	
West Virginia	359,000	255,000	17.5	
Michigan	288,000	172,000	11.8	
Maine	207,000	160,000	19.7	
Wisconsin	197,000	100,000	12.1	
Indiana	191,000	104,000	13.7	
Total for United States	8,277,000	6,218,000	15.7	

CORN

	Bushels	*Bushels*	*Bushels*	
Iowa	438,792,000	212,240,000	37.8	85
Illinois	336,738,000	217,751,000	36.0	81
Nebraska	223,843,000	26,859,000	24.0	87
Indiana	155,968,000	115,413,000	34.6	80
Missouri	146,489,000	40,032,000	25.0	78
Minnesota	143,136,000	88,331,000	31.2	76
Ohio	129,257,000	121,605,000	36.6	79
Kansas	126,756,000	11,036,000	19.3	80
Texas	81,922,000	68,925,000	16.8	78
South Dakota	78,447,000	8,446,000	19.2	80
Wisconsin	69,926,000	44,080,000	32.0	68
Kentucky	60,301,000	54,486,000	22.0	79
Tennessee	58,519,000	57,160,000	20.9	81
Oklahoma	51,842,000	11,772,000	16.6	75
Pennsylvania	45,487,000	54,572,000	39.0	81
Michigan	39,171,000	36,750,000	29.8	74
North Carolina	38,415,000	43,475,000	17.8	85
Georgia	36,288,000	33,624,000	10.4	81
Alabama	35,533,000	41,162,000	12.9	82
Total for United States	2,554,772,000	1,529,327,000	25.4	80.7

FIGS

	Tons	*Tons*	*Tons*	
California (dried)	[1] 18,000	20,000		
California (fresh)	[1] 6,950	9,600		
Texas (fresh)	[1] 3,526	1,450		

GRAPES

	Tons	*Tons*	*Tons*	
California	1,924,000	1,699,000		91
New York	80,106	41,800		91
Michigan	62,587	37,400		88
Ohio	25,735	22,000		89
Pennsylvania	25,174	15,800		89
Arkansas	11,820	10,600		81
Total for United States	2,199,679	1,878,790		90.6

[1] Data on figs for 1928–32 were not available. This is the average for 1931–34.

TABLE 1.—*Production of possible alcohol raw materials in the principal producing States and in the entire United States*—Continued

GRAIN SORGHUM (ALL VARIETIES)

State or Territory	Produced in—		Average yield per acre, 1923–32	10-year average percentage that was of marketable quality
	1928–32 (average)	1936		
	Bushels	*Bushels*	*Bushels*	
Texas	55,091,000	31,711,000	16.0	
Kansas	15,987,000	5,463,000	15.0	
Oklahoma	14,505,000	6,580,000	11.3	
New Mexico	4,338,000	1,950,000	15.7	
California	2,276,000	3,993,000	27.1	
Colorado	2,253,000	1,953,000	10.0	
Total for United States	97,760,000	55,701,000	14.7	

OATS

	Bushels	*Bushels*	*Bushels*	
Iowa	218,730,000	161,955,000	35.6	88
Illinois	152,009,000	99,608,000	33.6	83
Minnesota	148,841,000	94,376,000	34.1	86
Wisconsin	85,527,000	59,520,000	35.4	87
Nebraska	68,421,000	19,067,000	26.9	87
Indiana	63,810,000	38,502,000	30.4	84
Ohio	60,392,000	40,535,000	34.8	87
South Dakota	59,033,000	12,712,000	27.1	87
Michigan	43,854,000	32,181,000	31.7	87
Missouri	39,595,000	29,330,000	21.2	81
Texas	39,032,000	22,552,000	26.1	82
North Dakota	38,397,000	4,730,000	22.0	82
Kansas	34,515,000	32,186,000	22.9	83
New York	25,637,000	18,392,000	30.9	88
Oklahoma	25,434,000	20,320,000	20.8	83
Total for United States	1,215,102,000	789,100,000	30.2	86.4

PEACHES

	Bushels	*Bushels*	*Bushels*	
California	23,844,000	21,627,000		91
Georgia	5,749,000	5,751,000		76
North Carolina	1,980,000	1,800,000		74
Illinois	1,751,000	315,000		81
Pennsylvania	1,708,000	576,000		84
New Jersey	1,692,000	1,380,000		84
New York	1,617,000	700,000		87
Arkansas	1,461,000	825,000		70
Michigan	1,416,000	1,334,000		85
Tennessee	1,402,000	840,000		68
Texas	1,380,000	1,200,000		75
South Carolina	1,205,000	1,525,000		77
Washington	1,131,000	1,424,000		90
Total for United States	56,451,000	46,118,000		84.1

PLUMS AND PRUNES (FRESH)

	Tons	*Tons*	*Tons*	
California	64,200	64,000		
Oregon	27,260	35,000		
Idaho	22,840	12,200		
Washington	18,895	16,800		
Michigan	6,698	5,600		
Total for United States	139,893	133,600		

PRUNES (DRIED)[2]

	Tons	*Tons*	*Tons*	
California	196,660	153,000		
Oregon	25,500	23,000		
Washington	3,781	1,200		
Total for United States	225,941	177,200		

[2] In California, 2 pounds of plums make 1 pound of prunes; elsewhere from 3 to 4 pounds are required.

TABLE 1.—*Production of possible alcohol raw materials in the principal producing States and in the entire United States*—Continued

POTATOES

State or Territory	Produced in—		Average yield per acre, 1923–32	10-year average percentage that was of marketable quality
	1928–32 (average)	1936		
	Bushels	*Bushels*	*Bushels*	
Maine	44,078,000	44,000,000	258	93
Minnesota	29,620,000	12,502,000	93	87
New York	27,942,000	26,400,000	118	85
Pennsylvania	24,653,000	26,268,000	112	87
Wisconsin	24,311,000	20,090,000	100	86
Michigan	23,371,000	26,125,000	99	89
Idaho	21,723,000	22,260,000	200	91
Colorado	14,584,000	18,500,000	149	87
Virginia	14,328,000	7,380,000	126	85
Ohio	11,435,000	14,040,000	96	85
North Dakota	8,807,000	5,170,000	76	92
California	7,718,000	12,985,000	185	90
North Carolina	7,540,000	5,986,000	98	85
Total for United States	372,115,000	329,997,000	112.7	86.9

RICE (ROUGH)

	Bushels	*Bushels*	*Bushels*	
Louisiana	17,853,000	19,135,000	36.6	93
Texas	9,029,000	10,200,000	46.2	89
Arkansas	8,502,000	7,950,000	47.4	84
California	7,442,000	9,548,000	58.3	90
Total for United States	42,826,000	46,833,000	43.2	89.8

RYE

	Bushels	*Bushels*	*Bushels*	
North Dakota	11,073,000	2,448,000	10.8	87
Minnesota	5,966,000	4,325,000	15.5	89
South Dakota	4,072,000	1,608,000	12.0	88
Nebraska	2,667,000	3,442,000	10.0	91
Wisconsin	2,189,000	2,100,000	11.8	91
Michigan	1,950,000	1,622,000	12.6	91
Pennsylvania	1,671,000	1,260,000	13.6	92
Indiana	1,100,000	1,188,000	12.3	90
Iowa	681,000	1,050,000	15.8	92
Total for United States	38,212,000	25,554,000	12.0	89.8

SORGO SIRUP

	Gallons	*Gallons*	*Gallons*	
Alabama	2,516,000	2,736,000	66.0	
Mississippi	1,606,000	1,520,000	77.0	
North Carolina	1,376,000	1,260,000	67.0	
Tennessee	1,206,000	874,000	58.0	
Texas	1,115,000	1,350,000	56.0	
Total for United States	12,467,000	11,848,000	62.1	

SUGAR BEETS

	Tons	*Tons*	*Tons*	
Colorado	2,525,000	2,227,000	12.5	
Nebraska	996,000	783,000	12.9	
California	860,000	1,939,000	10.3	
Utah	621,000	511,000	11.8	
Michigan	612,000	936,000	7.9	
Wyoming	531,000	482,000	11.6	
Montana	514,000	649,000	11.1	
Idaho	449,000	724,000	10.3	
Total for United States	8,118,000	9,177,000	11.0	

TABLE 1.—*Production of possible alcohol raw materials in the principal producing States and in the entire United States*—Continued

SUGARCANE

State or Territory	Produced in— 1928–32 (average)	Produced in— 1936	Average yield per acre, 1923–32	10-year average percentage that was of marketable quality
	Tons	*Tons*	*Tons*	
Philippine Islands	[3] 11, 695, 744	14, 348, 452	[4] 18. 3	
Hawaii	[6] 8, 555, 424	9, 170, 279	[4] 68. 9	
Puerto Rico	[5] 7, 525, 058	7, 592, 201	[4] 25. 2	
Louisiana [7]	[5] 4, 087, 000	4, 394, 000	[4] 17. 3	
Florida	[5] 486, 000	600, 000	[4] 35	

SWEETPOTATOES (INCLUDING YAMS)

	Bushels	*Bushels*	*Bushels*	
Georgia	7, 304, 000	6, 630, 000	74. 0	84
North Carolina	7, 141, 000	7, 560, 000	96. 0	88
Alabama	6, 539, 000	6, 160, 000	84. 0	85
Mississippi	6, 136, 000	6, 474, 000	92. 0	87
Louisiana	5, 439, 000	7, 797, 000	71. 0	84
Tennessee	5, 340, 000	3, 696, 000	95. 0	87
Texas	4, 734, 000	3, 640, 000	76. 0	84
South Carolina	4, 648, 000	4, 845, 000	82. 0	86
Virginia	4, 270, 000	4, 366, 000	123. 0	88
Arkansas	2, 675, 000	2, 145, 000	90. 0	85
Total for United States	66, 368, 000	64, 144, 000	88. 5	86. 6

WHEAT

State or Territory	Produced in 1928–32 (average)	Produced in 1936	Yield per acre, 1923–32 (average)	Percentage that was of marketable quality (10-year average) Winter	Spring
	Bushels	*Bushels*	*Bushels*		
Kansas	177, 418, 000	120, 270, 000	14. 8	89. 0	82. 0
North Dakota	102, 840, 000	19, 235, 000	10. 7		86. 0
Nebraska	56, 520, 000	47, 339, 000	16. 5	90. 0	83. 0
Oklahoma	55, 145, 000	27, 520, 000	12. 8	89. 0	
Montana	45, 160, 000	13, 626, 000	11. 8	89. 0	90. 0
Washington	42, 798, 000	46, 193, 000	18. 7	90. 0	88. 0
Texas	41, 410, 000	18, 927, 000	12. 5	86. 0	
South Dakota	37, 003, 000	4, 286, 000	10. 6	85. 0	89. 0
Illinois	33, 183, 000	36, 435, 000	17. 6	89. 0	83. 0
Ohio	31, 664, 000	40, 278, 000	20. 7	90. 0	86. 0
Idaho	27, 228, 000	21, 096, 000	22. 5	92. 0	93. 0
Indiana	26, 732, 000	31, 042, 000	18. 2	89. 0	85. 0
Oregon	21, 211, 000	20, 340, 000	21. 2	94. 0	91. 0
Minnesota	21, 097, 000	18, 721, 000	14. 8	88. 0	82. 0
Missouri	20, 479, 000	31, 407, 000	13. 8	87. 0	81. 0
Pennsylvania	17, 659, 000	19, 615, 000	18. 2	91. 0	87. 0
Colorado	17, 255, 000	10, 691, 000	12. 6	91. 0	89. 0
Michigan	15, 949, 000	16, 702, 000	21. 0	89. 0	83. 0
California	11, 046, 000	16, 731, 000	18. 3	89. 0	
Total for United States	864, 532, 000	626, 461, 000	14. 7	89. 8	86. 1

[3] Figure for 1933–34.
[4] For 1935–36.
[5] Figure for 1935.
[6] Figure for 1933.
[7] In 1935, Louisiana made 20,088,000 gallons of blackstrap molasses and 5,526,000 gallons of other molasses, a total of 25,614,000 gallons. This was 76 gallons per ton of sugar made or 6.25 gallons per ton of sugarcane used.

CROP CLASSIFICATION

MARKET AND SAMPLE GRADES

The data in table 1 show that the percentage which is of marketable grade varies for the different crops. For the same crop the percentage also varies in different States and in different years. The marketable material is usually classified into numbered grades according to quality. The respective percentages in the numbered grades also vary annually and geographically. In the case of certain crops the 10-year average of nonmarketable material has been, in some States, as much as 30 percent of the crop. The total United States figures for all the crops for which marketable grades are shown indicate that the amount of unsalable material over the 10-year period averaged about 14 percent.

In addition to such unsalable material there is usually a percentage of a crop, particularly of grain crops, which is marketable but which falls below the limits of the numbered grade classifications. Such low-grade marketable material is usually sold on the submission of a sample and may fail to find a market or may actually fall into the unmarketable class, in good crop years. The percentage of the marketable crop which was sample grade is indicated by the following figures, which are averages for a 10-year period: Barley, 13.1 percent of the total marketable crop; corn, 5.4; grain sorghum, 7.6; oats, 5.3; rye, 4.65; wheat, 1.94 percent. These averages do not constitute a good year-by-year index. The yearly figures for barley, for example, during this period have fluctuated from 3.8 to 49.2 percent of the crop. Corn has ranged from 1.3 to 11.5 percent; grain sorghum from 3.4 to 16.3; oats from 1.3 to 15.1; rye from 0.56 to 23.9; and wheat (spring) from 0.1 to 14 percent.

SURPLUSES AND CARRY-OVERS

Crop surpluses are more difficult to establish accurately. The crop productions shown in table 1 are based on the acreage planted and the yield therefrom, but the actual amount marketed may be much less. The unsold material may represent either an excess amount of the entire crop, which cannot find use by any method now practicable and which actually might never be harvested, or it may consist of harvested, market-grade material. Such excess may result from overproduction, from diminished markets, from carried-over previous crops, or from price disturbances. Again, market conditions may favor the disposal of certain grades and leave a surplus of unsalable material in the remaining grades. Such a condition then tends to shift the relative price and sale percentages of the various grades. In some years crop production may result in an excess of inferior material and a corresponding shortage of high-grade material, or there may be a quantity shortage although the crop material may grade high.

A crop surplus is difficult to define. For any relatively nonperishable crop there is usually a carry-over of a small percentage of the previous production, which acts as a price stabilizer and material reserve. Small constant carry-over amounts are not in themselves serious and are usually considered as part of the normal supply. This normal supply is based on domestic consumption, plus anticipated exports, plus the usual carry-over amounts. Any production in excess of this total may be a surplus. A large carry-over followed by a short

crop would not indicate a surplus, whereas if followed by a large crop it might definitely be a surplus. As considered in this text a surplus merely represents material of any grade which might be diverted to alcohol production without real effect on the existing price structure.

In figure 19 the relation of total corn production and acreage to net exports, stocks, and annual price, is shown for a period of 40 years.[6] The yearly fluctuations due to conditions such as drought, overproduction or underproduction, depression, and war are evident. The stock remaining on hand after all operations in any 1 year might be taken as an index of the relative status of demand and production,

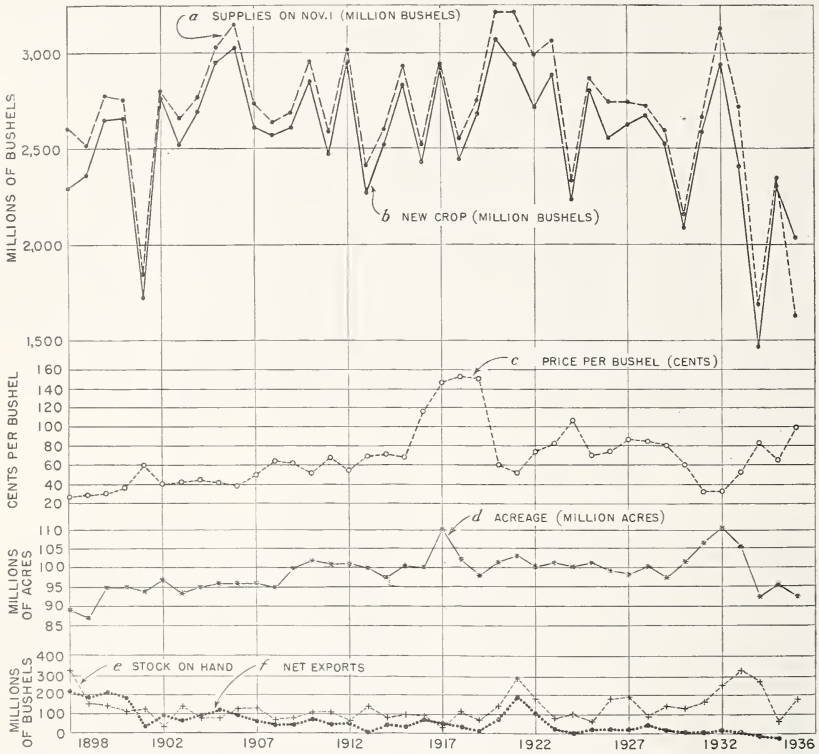


FIGURE 19.—Annual production, acreage, exports, stocks, and farm price of corn from 1897 to 1936: *a*, Total supplies on November 1; *b*, new crop; *c*, season average price per bushel received by farmers; *d*, acreage; *e*, stock on hand on November 1 from old crop; *f*, net exports.

and variations in carry-over amounts therefore become significant. The carry-over of corn and wheat probably represents the actual excess amounts of these crops.

In figure 19, line *a* represents the total supply (new crop plus the old stock on hand), and line *b* the portion of the total supply which was the new crop. Total carry-over of the old crop is shown in line *e*. The difference between lines *a* and *b* consists of net carry-over from the previous year's stock. It will be noticed that this net carry-over in the year 1903 was about 140 million bushels. In 1913 the net

[6] Data for these curves were taken from Department of Agriculture Yearbooks.

carry-over was approximately the same. In 1927 it was again about 120 million, or approximately 5 percent of the average crop. It may be assumed, therefore, that for the years between such dates the consumption practically equaled the production, so that if the original surplus in 1903 had been used or destroyed, there would not have been any appreciable amount to carry over in subsequent years. This, of course, disregards the factor of repression or stimulation of supply which would result from the existence or nonexistence of this overhead amount. The average carry-over of corn from 1915 to 1928 was 124 million bushels, which would produce about 290 million gallons of alcohol. The figures are cited merely to show that any motor-fuel alcohol-production program dependent on such excess material, as frequently advocated, would have been able to operate for 1 year only.

Due to the occurrence of unrelated factors, it has been impossible to show any definite cycle of overproduction or underproduction. The present domestic consumption and export of corn, plus a 7-percent normal carry-over, indicate a normal crop requirement of about 2,560 million bushels.

The carry-over of wheat from 1923 to 1937 ranged from 100 million to 377 million bushels, the amounts representing from 13 to 50 percent of the crop, with an average of about 27 percent (*76, table 15*). Estimates indicate that approximately 650 million bushels of the present wheat crop will be used for domestic consumption and 50 million bushels exported, to which may be added 15 percent as normal carry-over, or a total of 805 million bushels. Any crop production over that amount will necessarily increase the next year's carry-over, in the absence of unexpected demand, and tend to build up a surplus.

When the market price is low, the use of certain crops for industrial purposes (starch, solvents, etc.) is stimulated, unless there is a corresponding stagnation in the market for such derived products. When prices are high, industrial demand is decreased, but since high-price years are usually due in part to small-crop production, it is probable that a greater proportion of the crop is used for food or feed purposes than in normal years, so that culls and lower grades may find increased use as food or feed, thus offsetting the lack of industrial demand and effectively utilizing the supply. Any downward price disturbance for a crop normally tends to shift sales to the better grades, leaving the poorer grades as excess.

CULLS AND WASTES

Dependable estimates of the actual amounts of crop culls and wastes are practically unobtainable. When crops are concentrated at central distributing points in the normal course of marketing, figures on culls can sometimes be obtained. Crops such as potatoes, which are sorted at central shipping points, may show concentrations of unsold materials and culls at such points, but, in general, outside of these quantities the low-grade materials are scattered over the 6,800,000 farms of the country, where they are used or destroyed. Cull materials suitable for stock feed are used for this purpose unless the price of meat, milk, or other animal products is so unsatisfactory that stock are not raised.

CROPS IN TERMS OF ALCOHOL

ALCOHOL-PRODUCTION VALUE OF RAW MATERIALS

Low grades of agricultural raw materials are more likely to be used for the production of motor-fuel alcohol. Tables 2 and 3 indicate the probable yields obtainable from the agricultural crops that appear to be suitable, or possible, raw materials for alcohol production. These tables show also the fermentable content, crop yield per acre, weights, and storage-space requirements of these materials. Since a crop varies greatly both in yield per acre and in fermentable content, calculations have been made for both high and average fermentable content, for a range of acre yields. Consideration has also been given to the water-tolerance percentages allowed in the standards for the lower grades of crops likely to be used.

TABLE 2.—*Quantity of alcohol obtainable from various agricultural raw materials*

CEREALS [1]

Raw material and weight per bushel	Crop yield per acre [2 3]	Fermentable content		Probable commercial yield of 99.5-percent alcohol					
				Per bushel		Per ton		Per acre	
		Average	High	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content
	Bushels	*Pct.*	*Pct.*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*
Barley (bushel=48 pounds)	15.1	[4] 54.3	[5] 58.7	1.9	2.05	79.2	85.5	28.7	31.0
	22.6							43.0	46.3
	25.2							47.9	51.6
	49.0							93.0	100.5
Malt (bushel=34 pounds)		60.6		1.5	1.75	90.0	105.0		
Buckwheat (bushel=48 pounds)	10.0	[5] 57.2	[5] 60.0	2.00	2.10	83.3	87.5	20.0	21.0
	15.7							31.4	33.0
	17.1							34.2	35.9
	23.0							46.0	48.3
Corn (bushel=56 pounds)	10.4	[4] 57.8	[3] 64.2	2.35	2.62	84.0	93.6	23.9	26.5
	25.4							59.6	66.6
	37.8							88.8	99.0
	55.0							129.2	144.0
Grain sorghum (bushel=56 pounds)	10.0	[4] 54.5	[3] 66.0	2.22	2.70	79.5	96.4	22.2	27.0
	14.7							32.6	39.7
	16.0							35.5	43.2
	34.0							75.5	91.8
Oats (bushel=32 pounds)	14.1	[4] 43.6	[5] 45.8	1.02	1.05	63.6	66.8	14.3	14.8
	30.2							30.8	31.7
	35.6							36.3	37.4
	57.0							58.2	59.9
Rice, rough (bushel=45 pounds)	36.6	[4] 54.6	[3] 67.4	1.79	2.21	79.5	98.2	65.6	81.0
	43.2							77.5	95.5
	36.6							65.6	81.0
	75.0							134.2	165.7
Rye (bushel=56 pounds)	6.3	[4] 54.0	[5] 62.5	2.20	2.54	78.8	91.0	13.9	16.0
	12.0							26.4	30.5
	10.8							23.8	27.4
	22.0							48.4	55.9
Wheat, all varieties (bushel=60 pounds)	8.7	[4] 58.6	[5] 62.5	2.57	2.74	85.0	91.4	22.3	23.8
	14.7							37.4	40.3
	13.0							33.0	35.6
	30.4							77.2	83.3

See footnotes at end of table.

TABLE 2.—*Quantity of alcohol obtainable from various agricultural raw materials*—Continued

SUGAR CROPS [6]

Raw material and weight per bushel	Crop yield per acre	Fermentable content		Probable commercial yield of 99.5-percent alcohol					
				Per bushel		Per ton		Per acre	
		Average	High	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content
	Gallons	*Pct.*	*Pct.*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*
Sorgo sirup (gallon=11.75 pounds)	46.0 62.0 66.0 100.0	[5] 51.0	[5] 55.0			70.4	75.9	18.4 24.8 26.4 40.0	20.4 27.5 29.3 44.4
	Tons								
Sugarcane:									
United States	6.8 13.6 17.6 35.3	[5] 11.0	[5] 12.5			15.2	17.3	103.0 198.0 268.0 537.0	118.0 225.0 305.0 605.0
Hawaii (18 to 22 months)	58.5							889.0	1,010.0
	Gallons								
Molasses:									
Blackstrap (gallon=11.75 pounds)	90.0 110.0 240.0	[5] 51.0	[5] 55.0	.41	.44	70.4	75.9	37.0 45.0 98.0	40.0 49.0 107.0
High-test invert		72.0	78.0	.58	.63				
	Tons								
Sugar beet	8.0 11.0 13.0 16.5	[5] 16.0	[5] 18.0			22.1	24.9	177.0 243.0 287.0 364.0	199.0 273.0 323.0 411.0

TUBERS AND ROOTS [7]

	Bushels								
Jerusalem-artichokes (bushel=60 pounds)	100 200 300 [9] 500	[8] 15.2	19.0	0.60	0.75	20	25	60.0 90.0 180.0 300.0	75.0 150.0 225.0 375.0
Potatoes (bushel=60 pounds)	60 112.7 258 325	[8] 15.6	18.0	.69	.79	22.9	26.3	41.5 77.8 178.0 221.5	47.4 89.0 204.0 256.8
Sweetpotatoes (bushel=55 pounds)	71 96 150 [9] 400	[8] 23.3	32.0	.94	1.29	34.2	46.6	66.7 90.0 141.0 376.0	91.5 124.0 193.5 545.0
Yams (bushel=55 pounds)	70 100 125 150	[8] 18.7	25.0	.75	1.00	27.3	36.6	52.5 75.0 94.0 112.5	70.0 100.0 125.0 150.0
Carrots (bushel=55 pounds)	175 366 485 600	[8] 7.5	8.7	.25	.29	9.8	11.4	43.7 91.5 121.0 150.0	50.7 106.0 140.5 174.0

See footnotes at end of table.

TABLE 2.—*Quantity of alcohol obtainable from various agricultural raw materials*—Continued

FRUIT

Raw material and weight per bushel	Crop yield per acre	Fermentable content		Probable commercial yield of 99.5-percent alcohol					
				Per bushel		Per ton		Per acre	
		Average	High	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content	Average fermentable content	High fermentable content
	Bushels	*Pct.*	*Pct.*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*
Apples, all varieties (bushel=48 pounds)-	30	[5] [10] 11.0	12.0	0.35	0.38	14.4	15.7	10.5	11.4
	100							35.0	38.0
	400							140.0	152.0
	470							164.5	178.6
	Tons								
Apricots	2.00	[5] [10] 10.4	13.0			13.6	17.0	27.3	34.1
	2.75							37.5	46.9
	3.00							41.0	51.2
	3.50							47.8	60.7
Dates, dry	.80	[5] [8] [10] 60.0	70.0			79.0	92.0	63.0	74.0
	1.10							95.0	110.0
	1.60							126.0	148.0
	2.00							158.0	185.0
Figs, fresh	.90	[5] [8] [10] 16.0	20.0			21.0	26.2	18.8	23.6
	1.25							26.8	32.8
	1.50							31.5	39.4
	2.00							42.0	52.5
Figs, dry	.30	[5] [8] [10] 45.0	50.0			59.0	65.6	17.7	19.7
	.40							23.6	26.2
	.50							29.5	32.8
	.60							35.4	39.4
Grapes, all varieties	1.50	[5] [8] [10] 11.5	15.0			15.1	19.7	22.6	29.5
	3.50							52.8	68.9
	6.00							90.4	118.0
	7.50							113.0	147.5
	Bushels								
Peaches (bushel=48 pounds)	50	[5] [10] 8.7	11.6	.28	.37	11.5	15.3	14.0	18.6
	200							56.0	74.7
	300							84.0	112.0
	400							112.0	149.4
Pears (bushel=50 pounds)	50	[5] [10] 8.9	10.0	.29	.33	11.5	13.0	14.5	16.5
	140							40.6	46.2
	170							49.3	56.1
	200							58.0	66.0
	Tons								
Pineapples	3.00	[5] [8] [10] 11.9	15.0			15.6	19.6	46.8	58.9
	4.00							62.4	78.6
	5.00							78.0	98.2
	6.00							93.6	117.8
Plums (nonprunes)	1.00	[5] [10] 8.3	12.5			10.9	16.3	10.9	16.3
	1.50							16.3	24.4
	2.00							21.8	32.7
	2.50							27.3	41.0
Prunes, dry	.70	[5] [10] 55.0	60.0			72.0	78.7	50.4	55.1
	1.00							72.0	78.7
	1.15							82.8	90.5
	1.50							108.0	118.0
Raisins, dry	.70	[5] [8] [10] 62.0	68.0			81.4	89.3	57.0	62.5
	1.00							81.4	89.3
	1.25							101.7	111.7
	1.50							122.0	134.0

[1] Theoretical yield of alcohol is based on entire fermentable content as starch. (1 pound of starch=0.568 pound of alcohol.)

[2] Figures on yield for each crop are, in sequence: Lowest average for a single State for 1923–32, average for the total United States for 1923–32, average for the chief producing State or area for 1923–32, best yield for a single State for any 1 year during the period 1921–36.

[3] Most of the figures on crop yields are from Agricultural Statistics (*76*).

[4] Coleman (*24*).

[5] Atwater and Bryant (*9*).

[6] Theoretical yield of alcohol is based on entire fermentable content as sucrose. (1 pound of sucrose =0.538 pound of alcohol.)

[7] Theoretical yield of alcohol of all except potatoes is based on entire fermentable content of invert sugar. (1 pound of invert sugar=0.511 pound of alcohol.) The yield from potatoes is based on entire fermentable content as starch.

[8] Chatfield and Adams (*18*).

[9] Experimental plots.

[10] Chatfield and McLaughlin (*19*).

Acre yields shown in table 2 represent the probable range from poor to good crops. It will be noted that in some instances the yields per acre in the chief producing areas are close to or lower than the average yields for the United States. Certain regions, the North Atlantic States, for example, produce high acre yields of certain crops, but the total amount produced is comparatively small.

It has been assumed that in each case alcohol recovery will be 85 percent of the theoretical yield, calculated on the part of the material naturally fermentable by yeast. In commercial practice this should be exceeded in some cases. In general, yield figures, which are calculated on the basis of the carbohydrates (less pentosans) present, are conservative values. Under favorable circumstances the yields per acre, the percentage of fermentable matter, and the recovery of alcohol may exceed the values given, but because of the probably inferior types of raw materials likely to be used for motor-fuel alcohol, high values have not usually been considered in this survey. From a crop grown specifically for motor-fuel alcohol on good land, from good seed, and with heavy fertilization, acre yields of alcohol should exceed the values shown.

Table 2 has served as a basis for calculating the data on alcohol production in subsequent tables.

Table 3 shows the probable weight per unit and per cubic foot of the potential raw materials for alcohol production (table 2) and the

TABLE 3.—*Weights and storage requirements for raw materials and yield of alcohol and residual solids*

Material	Unit	Pounds per unit [1]	Pounds per cubic foot	Units per ton	Storage required per ton	Fermentable matter		Yield of 99.5-per-cent alcohol per ton	Residual solids	
						Percent (*9, 18, 19, 24*)	Pounds per ton		Percent [2]	Pounds per ton
					Cubic feet			*Gallons*		
Wheat (all varieties)	Bushel	60	48.2	33.3	41.5	58.6	1,172	85.0	26.9	538
Corn	do	56	45.0	35.7	44.4	57.8	1,156	84.0	22.3	446
Buckwheat	do	48	38.6	41.7	51.8	57.2	1,144	83.3	25.0	500
Raisins	Ton	2,000	62.5	1.0	32.0	62.0	1,240	81.4	8.3	166
Grain sorghum	Bushel	56	45.0	35.7	44.4	54.5	1,090	79.5	24.4	488
Rice, rough	do	45	36.2	44.4	55.3	54.6	1,092	79.5	26.0	520
Barley	do	48	38.6	41.7	51.8	54.3	1,086	79.2	32.3	646
Dates, dry	Ton	2,000	62.5	1.0	32.0	60.0	1,200	79.0	6.6	132
Rye	Bushel	56	45.0	35.7	44.4	54.0	1,080	78.8	27.1	542
Prunes, dry	Ton	2,000	62.5	1.0	32.0	55.0	1,100	72.0	7.6	152
Molasses, blackstrap	Gallon	11.75	87.9	170.0	22.8	51.0	1,020	70.4	------	--------
Sorgo sirup	do	11.75	87.9	170.0	22.8	51.0	1,020	70.4	------	--------
Oats	Bushel	32	25.7	62.5	78.0	43.6	872	63.6	42.3	846
Cassava	do	55	44.2	36.4	45.2	30.0	600	43.5	5.0	100
Figs, dry	Ton	2,000	62.5	1.0	32.0	45.0	900	59.0	14.2	284
Sweetpotatoes	Bushel	55	44.2	36.4	45.2	23.3	466	34.2	4.6	92
Yams	do	55	44.2	36.4	45.2	18.7	374	27.3	4.0	80
Potatoes	do	60	48.2	33.3	41.5	15.6	312	22.9	3.8	76
Sugar beets	do	60	48.2	33.3	41.5	16.0	320	22.1	5.0	100
Figs, fresh	Ton	2,000	62.5	1.0	32.0	16.0	320	21.0	4.1	82
Jerusalem-artichokes	Bushel	60	48.2	33.3	41.5	15.2	304	20.0	5.2	104
Pineapples	Crate	70	--------	--------	28.6	11.9	238	15.6	1.4	28
Sugarcane					22.8	11.0	220	15.2	------	--------
Grapes (all varieties)	Bushel	48	38.6	41.7	51.8	11.5	230	15.1	3.8	76
Apples	do	48	38.6	41.7	51.8	11.0	220	14.4	2.0	40
Apricots	do	48	38.6	41.7	51.8	10.4	208	13.6	2.3	46
Pears	do	50	40.2	40.0	49.7	8.9	178	11.5	2.9	58
Peaches	do	48	38.6	41.7	51.8	8.7	174	11.5	1.7	34
Plums	do	56	45.0	35.7	44.4	8.3	166	10.9	1.9	38
Carrots	do	50	40.2	40.0	49.7	7.5	150	9.8	3.8	76

[1] UNITED STATES BUREAU OF AGRICULTURAL ECONOMICS. APPROXIMATE OR AVERAGE WEIGHTS OF VARIOUS COMMODITIES. 4 pp. 1936. [Mimeographed.]

[2] Percentage of raw material obtained as residual solids estimated from analyses shown in footnote 1 and (*9, 18, 19, 24*).

storage space required per ton. The probable average alcohol yields and amounts of residual solids recoverable are also shown.

The various materials are arranged in the order of probable average alcohol yield per ton and per acre in the following tabulations. These tabulations are designed to show the relative importance or value of various crops as raw materials for alcohol production.

Average yield [1] of 99.5-percent alcohol per ton

Material	Gallons	Material	Gallons
Wheat (all varieties)	85. 0	Yams	27. 3
Corn	84. 0	Potatoes	22. 9
Buckwheat	83. 4	Sugar beets	22. 1
Raisins	81. 4	Figs, fresh	21. 0
Grain sorghum	79. 5	Jerusalem—artichokes	20. 0
Rice, rough	79. 5	Pineapples	15. 6
Barley	79. 2	Sugarcane	15. 2
Dates, dry	79. 0	Grapes (all varieties)	15. 1
Rye	78. 8	Apples	14. 4
Prunes, dry	72. 0	Apricots	13. 6
Molasses, blackstrap	70. 4	Pears	11. 5
Sorghum cane	70. 4	Peaches	11. 5
Oats	63. 6	Plums (nonprunes)	10. 9
Figs, dry	59. 0	Carrots	9. 8
Sweetpotatoes	34. 2		

[1] Yield from a short ton of the raw material, calculated from the average fermentable content shown in table 2.

Average yield [1] of 99.5-percent alcohol per acre

Material	Gallons	Material	Gallons
Sugarcane (Hawaii, 18 to 22 months)	889. 0	Pineapples	78. 0
Sugar beets	287. 0	Rice, rough	65. 6
Sugarcane (Louisiana)	268. 0	Pears	49. 3
Jerusalem-artichokes	180. 0	Barley	47. 9
Potatoes	178. 0	Molasses, blackstrap	45. 0
Sweetpotatoes	141. 0	Apricots	41. 0
Apples	140. 0	Oats	36. 3
Dates, dry	126. 0	Grain sorghum	35. 5
Carrots	121. 0	Buckwheat	34. 2
Raisins	101. 7	Wheat (all varieties)	33. 0
Yams	94. 0	Figs, fresh	31. 5
Grapes (all varieties)	90. 4	Figs, dry	29. 5
Corn	88. 8	Sorghum cane	26. 4
Peaches	84. 0	Rye	23. 8
Prunes, dry	82. 8	Plums (nonprunes)	21. 8

[1] Yield calculated from the average fermentable content and average acre yield of raw material as shown in table 2.

REQUIRED TONNAGE AND ACREAGE FOR ALCOHOL PRODUCTION

Table 4 shows the approximate quantities of the various potential materials, estimated on the basis of average expected yields, which would be required annually for operation of alcohol plants of various sizes. Table 5 shows the computed daily requirement for these materials, as well as the annual acreage required to produce sufficient quantities of these raw materials for operation of alcohol plants of various sizes for 1 year.

TABLE 4.—*Quantity of raw material [1] required annually for operation of alcohol plants of various sizes for a year of 300 days*

Material	Unit	Requirement for daily alcohol [2] production of—			
		1,000 gallons	2,500 gallons	5,000 gallons	20,000 gallons
Apples	Bushel	900,000	2,250,000	4,500,000	18,000,000
Apricots	Ton	22,000	55,000	110,000	440,000
Barley	Bushel	158,000	395,000	790,000	3,160,000
Buckwheat	do	133,000	332,500	665,000	2,660,000
Carrots	do	1,200,000	3,000,000	6,000,000	24,000,000
Corn	do	128,000	320,000	640,000	2,560,000
Dates, dry	Ton	3,800	9,500	19,000	76,000
Figs, fresh	do	14,300	35,750	71,500	286,000
Figs, dry	do	5,100	12,750	25,500	102,000
Grain, sorghum	Bushel	135,300	338,250	676,500	2,706,000
Grapes (all varieties)	Ton	20,000	50,000	100,000	400,000
Jerusalem-artichokes	Bushel	500,000	1,250,000	2,500,000	10,000,000
Oats	do	300,000	750,000	1,500,000	6,000,000
Peaches	do	1,180,000	2,950,000	5,900,000	23,600,000
Pears	do	1,035,000	2,587,500	5,175,000	20,700,000
Pineapples	Ton	19,250	48,125	96,250	385,000
Plums	do	27,500	68,750	137,500	550,000
Potatoes	Bushel	435,000	1,087,500	2,175,000	8,700,000
Sweetpotatoes	do	320,000	800,000	1,600,000	6,400,000
Prunes, dry	Ton	4,200	10,500	21,000	84,000
Raisins	do	3,750	9,375	18,750	75,000
Rice, rough	Bushel	167,400	418,500	837,000	3,348,000
Rye	do	136,200	340,500	681,000	2,724,000
Sorgo sirup	Gallon	750,000	1,875,000	3,750,000	15,000,000
Sugar beets	Ton	13,650	34,125	68,250	273,000
Sugarcane	do	20,000	50,000	100,000	400,000
Sugarcane molasses, blackstrap	Gallon	750,000	1,875,000	3,750,000	15,000,000
Wheat	Bushel	117,000	292,500	585,000	2,340,000
Yams	do	400,000	1,000,000	2,000,000	8,000,000

[1] Based on the average fermentable content of the respective materials as shown in table 2.
[2] Concentration of 99.5 percent.

TABLE 5.—*Quantity of raw material [1] required daily and acreage required annually for operation of alcohol plants of various sizes for a year of 300 days*

Material	Unit	Requirement for daily alcohol [2] production of—			
		1,000 gallons		5,000 gallons	
		Daily raw material	Annual acreage	Daily raw material	Annual acreage
Apples	Bushel	2,860	2,140	14,300	10,700
Apricots	Ton	73.5	7,325	367.5	36,625
Barley	Bushel	526	6,260	2,630	31,300
Buckwheat	do	476	8,370	2,380	41,850
Carrots	do	4,000	2,480	20,000	12,400
Corn	do	426	3,380	2,130	16,900
Dates, dry	Ton	12.65	2,380	63.25	11,900
Figs, fresh	do	47.6	9,530	238	47,650
Figs, dry	do	17	10,150	85	50,750
Grain sorghum	Bushel	451	8,450	2,255	42,250
Grapes (all varieties)	Ton	66.2	3,320	331	16,600
Jerusalem-artichokes	Bushel	1,667	1,667	8,335	8,335
Oats	do	980	8,260	4,900	41,300
Peaches	do	3,570	3,570	17,850	17,850
Pears	do	3,450	6,080	17,250	30,400
Pineapples	Ton	64.1	3,850	320.5	19,250
Plums	do	91.7	13,750	458.5	68,750
Potatoes	Bushel	1,450	1,685	7,250	8,425
Sweetpotatoes	do	1,065	2,130	5,325	10,650
Prunes	Ton	13.85	3,630	69.25	18,150
Raisins, dry	do	12.3	2,960	61.5	14,800
Rice, rough	Bushel	558	4,560	2,790	22,800
Rye	do	454	12,600	2,270	63,000
Sorgo sirup	Gallon	2,440	11,350	12,200	56,750
Sugar beet	Ton	45.3	1,046	2,265	5,230
Sugarcane	do	65.8	1,120	329	5,600
Sugarcane molasses, blackstrap	Gallon	2,440	6,667	12,200	33,335
Wheat	Bushel	389	9,100	1,945	45,500
Yams	do	1,333	3,190	6,665	15,950

[1] Based on the average fermentable content and the 10-year yield per acre for the chief producing State, of the respective materials as shown in table 2.
[2] Concentration of 99.5 percent.

MINIMUM-SIZE PLANT

Alcohol production should not be started unless raw materials are available to provide for a plant of the minimum size capable of producing alcohol profitably. Such a plant should probably contemplate a production of at least 2,000 gallons daily, to be able to maintain the essential technical supervision for efficient operation without increasing unit costs unduly. Minimum amounts of raw materials required to operate an alcohol plant of this size for a year of 300 days are shown in table 6.

TABLE 6.—*Minimum quantities of raw material required annually for production of 2,000 gallons of alcohol per day for a 300-day year*

Crop	Unit	Required for distillery	Required State production for primary classification [1]
Apples	Bushels	1,800,000	36,000,000
Apricots	Tons	44,000	880,000
Barley	Bushels	316,000	6,320,000
Buckwheat	do	266,000	5,320,000
Carrots	do	2,400,000	48,000,000
Corn	do	256,000	5,120,000
Dates, dry	Tons	7,600	152,000
Figs, fresh	do	28,600	572,000
Figs, dry	do	10,200	204,000
Grain sorghum	Bushels	270,600	5,412,000
Grapes (all varieties)	Tons	40,000	800,000
Jerusalem-artichokes	Bushels	1,000,000	20,000,000
Oats	do	600,000	12,000,000
Peaches	do	2,360,000	47,200,000
Pears	do	2,070,000	41,400,000
Pineapples	Tons	38,500	770,000
Plums	do	55,000	1,100,000
Potatoes	Bushels	870,000	17,400,000
Prunes, dry	Tons	8,400	168,000
Raisins	do	7,500	150,000
Rice, rough	Bushels	334,800	6,696,000
Rye	do	272,400	5,448,000
Sorgo sirup	Gallons	1,506,000	30,000,000
Sugar beets	Tons	27,300	546,000
Sugarcane	do	40,000	800,000
Sugarcane molasses, blackstrap	Gallons	1,500,000	30,000,000
Sweetpotatoes	Bushels	640,000	12,800,000
Wheat	do	234,000	4,680,000

[1] Assuming that only 5 percent of the total crop is available as raw material.

LOCATION OF RAW MATERIALS

Location of a motor-fuel alcohol plant involves a question of the availability of raw materials at low expense. Considering the problem on a State-crop basis, in certain States there may be a variety of materials, but the available quantity of some of these may be less than the minimum necessary for year-long plant operation with that crop alone. In some cases main crops might be supplemented by smaller quantities of other crops, if within reasonable haulage distance. In the larger States specific crops are sometimes localized in small areas which may be remote from other crop production areas. Actually, plant location is a matter which must be decided by relatively local conditions.

The data in tables 6 and 7 indicate the alcohol-production potentiality of a State or group of States, or perhaps of a general location. For a specific location, additional and more particularized data on crop production in the territory adjacent to the selected point should

be secured, since the crops shown in the total for the State may be produced at such a distance that transportation costs would be prohibitive. In table 7, which shows the average production of all crops exceeding an arbitrary minimum production, for each State for the 5-year period 1928–32, crops produced in such quantity that 5 percent of the total for the State supplies more than the amount of raw material required for a minimum-size plant are designated as primary raw materials. Those produced in smaller amounts are called secondary.

TABLE 7.—*Classification of potential raw materials for alcohol based on the quantity produced from 1928 to 1932*

State or territory	Primary		Secondary	
	Crop	Total State production	Crop	Total State production
Alabama	Corn	35,402,000 bushels	Sweetpotatoes	6,368,000 bushels.
			Sorgo sirup	2,585,000 gallons.
Arkansas	Corn	30,086,000 bushels	Peaches	1,461,000 bushels.
	Rice, rough	8,502,000 bushels	Sweetpotatoes	2, 176,000 bushels.
			Grapes (all varieties)	11,820 tons.
California	Barley	28,416,000 bushels	Apples	10,156,000 bushels.
	Grapes	1,924,000 tons	Apricots	240,500 tons.
	Prunes, dry	196,600 tons	Figs, fresh	6,950 tons.
	Rice, rough	7,527,000 bushels	Figs, dried	18,000 tons.
	Sugar beets	860,000 tons	Dates	2,000 tons.
			Peaches	23,844,000 bushels.
			Pears	9,534,000 bushels.
			Plums	64,200 tons.
			Potatoes	7,152,000 bushels.
			Sweetpotatoes	1,075,000 bushels.
			Grain sorghum	2,302,000 bushels.
Colorado	Corn	22,599,000 bushels	Apples	2,019,000 bushels.
	Barley	9,815,000 bushels	Potatoes	14,083,000 bushels.
	Sugar beets	2,525,000 tons	Grain sorghum	2,009,000 bushels.
	Wheat	17,111,000 bushels		
Florida	Corn	6,256,000 bushels	Potatoes	1,636,000 bushels.
Georgia	do	36,620,000 bushels	Peaches	5,749,000 bushels.
			Sweetpotatoes	6,769,000 bushels.
Idaho	Potatoes	20,610,000 bushels	Apples	5,066,000 bushels.
	Sugar beets	449,000 tons	Plums	22,840 tons.
	Wheat	27,028,000 tons		
Illinois	Barley	11,287,000 bushels	Apples	4,545,000 bushels.
	Corn	329,659,000 bushels	Peaches	1,751,000 bushels.
	Oats	152,806,000 bushels		
	Wheat	32,532,000 bushels		
Indiana	Corn	154,125,000 bushels	Apples	1,819,000 bushels.
	Oats	63,693,000 bushels	Rye	1,118,000 bushels.
	Wheat	26,522,000 bushels		
Iowa	Barley	18,229,000 bushels	do	677,000 bushels.
	Corn	438,792,000 bushels		
	Oats	218,730,000 bushels		
	Wheat	7,445,000 bushels		
Kansas	Barley	10,515,000 bushels		
	Corn	127,493,000 bushels		
	Oats	34,649,000 bushels		
	Grain sorghum	15,987,000 bushels		
	Wheat	177,431,000 bushels		
Kentucky	Corn	61,290,000 bushels	Apples	2,273,000 bushels.
			Sweetpotatoes	1,499,000 bushels.
			Sorgo sirup	924,000 gallons.
Louisiana	do	17,896,000 bushels	Sweetpotatoes	4,950,000 bushels.
	Rice, rough	17,853,000 bushels		
	Sugarcane	3,028,000 tons		
Maine	Potatoes	44,078,000 bushels	Apples	1,830,000 bushels.
Maryland	Corn	15,039,000 bushels	Apples	2,053,000 bushels.
	Wheat	8,648,000 bushels	Sweetpotatoes	1,374,000 bushels.
Massachusetts			Apples	2,796,000 bushels.
Michigan	Barley	6,433,000 bushels	Apples	6,641,000 bushels.
	Corn	36,799,000 bushels	Grapes (all varieties)	62,587 tons.
	Oats	43,098,000 bushels	Peaches	1,416,000 bushels.
	Potatoes	23,072,000 bushels	Plums	6,698 tons.
	Sugar beets	612,000 tons	Rye	1,978,000 bushels.
	Wheat	15,523,000 bushels		
Minnesota	Barley	49,608,000 bushels		
	Corn	146,425,000 bushels		
	Oats	149,179,000 bushels		
	Potatoes	29,620,000 bushels		
	Rye	5,966,000 bushels		
	Wheat	20,946,000 bushels		

TABLE 7.—*Classification of potential raw materials for alcohol based on the quantity produced from 1928 to 1932*—Continued

State or territory	Primary		Secondary	
	Crop	Total State production	Crop	Total State production
Mississippi	Corn	32,044,000 bushels	Sweetpotatoes	5,663,000 bushels.
			Sorgo sirup	1,547,000 gallons.
Missouri	do	156,561,000 bushels	Apples	2,434,000 bushels.
	Oats	39,595,000 bushels	Grain sorghum	1,243,000 bushels.
	Wheat	20,362,000 bushels		
Montana	Sugar beets	514,000 tons	Oats	7,483,000 bushels.
	Wheat	45,167,000 bushels		
Nebraska	Barley	15,758,000 bushels	Rye	3,150,000 bushels.
	Corn	225,053,000 bushels		
	Oats	68,916,000 bushels		
	Sugar beets	996,000 tons		
	Wheat	56,538,000 bushels		
New Mexico	Grain sorghum	4,638,000 bushels		
	Wheat	4,148,000 bushels		
New Jersey	Corn	6,535,000 bushels	Apples	3,295,000 bushels.
			Peaches	1,692,000 bushels.
			Potatoes	7,031,000 bushels.
			Sweetpotatoes	1,628,000 bushels.
New York	do	19,209,000 bushels	Apples	19,012,000 bushels.
	Oats	26,485,000 bushels	Grapes (all varieties)	80,106 tons.
	Potatoes	25,904,000 bushels	Peaches	1,617,000 bushels.
	Wheat	4,411,000 bushels	Pears	1,262,000 bushels.
North Carolina	Corn	39,119,000 bushels	Apples	3,411,000 bushels.
			Peaches	1,980,000 bushels.
			Potatoes	7,573,000 bushels.
			Sweetpotatoes	6,819,000 bushels.
			Sorgo sirup	1,428,000 gallons.
North Dakota	Barley	39,537,000 bushels	Potatoes	8,710,000 bushels.
	Corn	20,836,000 bushels		
	Oats	37,784,000 bushels		
	Rye	11,362,000 bushels		
	Wheat	102,903,000 bushels		
Ohio	Corn	123,701,000 bushels	Apples	6,538,000 bushels.
	Oats	60,934,000 bushels	Grapes (all varieties)	25,735 tons.
	Wheat	30,480,000 bushels	Potatoes	10,709,000 bushels.
			Sugar beets	218,000 tons.
Oklahoma	Corn	52,381,000 bushels	Sweetpotatoes	1,396,000 bushels.
	Oats	26,711,000 bushels		
	Grain sorghum	13,702,000 bushels		
	Wheat	55,145,000 bushels		
Oregon	do	21,205,000 bushels	Apples	5,082,000 bushels.
			Oats	7,954,000 bushels.
			Plums	27,260 tons.
			Prunes, dried	25,500 tons.
			Pears	2,711,000 bushels.
Pennsylvania	Corn	45,585,000 bushels	Apples	9,584,000 bushels.
	Potatoes	22,698,000 bushels	Grapes (all varieties)	25,174 tons.
	Wheat	17. 387,000 bushels	Peaches	1,708,000 bushels.
			Rye	1,671,000 bushels.
South Carolina	Corn	20,151,000 bushels	Oats	8,080,000 bushels.
			Peaches	1,205,000 bushels.
			Sweetpotatoes	4,569,000 bushels.
South Dakota	Barley	35,771,000 bushels	Rye	4,048,000 bushels.
	Corn	80,606,000 bushels		
	Oats	59,033,000 bushels		
	Wheat	37,632,000 bushels		
Tennessee	Corn	57,959,000 bushels	Apples	1,942,000 bushels.
			Peaches	1,402,000 bushels.
			Sweetpotatoes	5,357,000 bushels.
			Sorgo sirup	1,234,000 gallons.
Texas	do	83,669,000 bushels	Figs, fresh	3,526 tons.
	Oats	37,904,000 bushels	Peaches	1,380,000 bushels.
	Rice, rough	9,135,000 bushels	Sweetpotatoes	4,734,000 bushels.
	Grain sorghum	52,882,000 bushels	Sorgo sirup	1,115,000 gallons.
	Wheat	41,083,000 bushels		
Utah	Sugar beets	621,000 tons		
	Wheat	5,540,000 bushels		
Virginia	Corn	31,346,000 bushels	Apples	13,160,000 bushels.
	Wheat	9,220,000 bushels	Potatoes	14,447,000 bushels.
			Sweetpotatoes	4,136,000 bushels.
Washington	do	42,882,000 bushels	Oats	7,652,000 bushels.
	Apples	33,510,000 bushels	Pears	3,771,000 bushels.
			Plums	18,895 tons.
			Potatoes	7,468,000 bushels.
			Prunes, dried	3,781 tons.

TABLE 7.—*Classification of potential raw materials for alcohol based on the quantity produced from 1928 to 1932*—Continued

State or territory	Primary		Secondary	
	Crop	Total State production	Crop	Total State production
West Virginia	Corn	11,056,000 bushels	Apples	6,947,000 bushels.
			Peaches	1,131,000 bushels.
Wisconsin	Barley	22,178,000 bushels	Apples	1,801,000 bushels.
	Corn	69,375,000 bushels	Rye	2,334,000 bushels.
	Oats	85,527,000 bushels		
	Potatoes	23,385,000 bushels		
Wyoming	Sugar beets	531,000 tons		
Hawaii	Sugarcane	8,536,781 tons		
Philippine Islands.	do	14,348,452 tons		
Puerto Rico	do	9,070,454 tons		

The quantities of certain raw materials shown in table 6 may be misleading. Perishable materials, such as fruit, would not be available for a 300-day operation and could not be stored. Cereal crops, on the other hand, may be available for the entire year. The use of fruit as a raw material would require supplementary materials to cover otherwise inactive periods, and the respective amounts should be prorated according to the time periods. The use of more than 5 percent of the crops would change the relative classification shown in table 7.

CULL ACCUMULATIONS

Most of the proposals advocating the production of motor-fuel alcohol from agricultural products have visualized either the utilization of culls and occasional surpluses for a limited and irregular alcohol production on a local basis or a large-scale alcohol program the raw materials for which would presumably be taken out of the marketable crop. In the latter case, under existing conditions, price disturbances of the raw material would immediately result from the increased demand. This course, therefore, is disregarded here because obviously an increase in the material cost would involve increases in the alcohol cost, which would soon reach impractical amounts. Therefore, either the alcohol motor-fuel program would have to be definitely established on some adequate scale and sufficient crops grown to provide specifically for it, which could be produced within the cost limits, or the program would have to be limited to the use of such normal wastes and culls and occasional surpluses as might become available from time to time, with consequent variability in the amounts of alcohol obtainable.

Facilities for utilization of low or sample grades and culls would probably have to provide sufficient capacity to handle the large local amounts occurring in some years, although the usual supply would restrict normal operation to a smaller scale.

Certain culls, as well as low or unsalable grades, accumulate at certain points in the normal course of sorting, grading, and marketing. Potatoes, for example, are concentrated at points in Maine, southeastern Idaho, western Michigan, southeastern Virginia, northeastern

North Dakota, etc. Corn largely accumulates at concentration points along the Missouri and Mississippi Rivers, particularly at Kansas City, Omaha, and Sioux City, Iowa. Low-grade corn is less likely to accumulate in stock-feeding areas. Most of the low-grade corn accumulates in or near Peoria, Ill. Surplus wheat concentrates at Kansas City, with occasional surpluses and milling residue accumulations at Minneapolis. Grain sorghum (kafircorn) concentrates largely at Fort Worth, Tex., and Enid, Okla. Oats concentrate in eastern Iowa, for example, in Clinton and Cedar Rapids.

Table 8 indicates the probable accumulation of cull or low-grade materials at shipping points, potatoes being used as a specific example. This table lists the carload shipments of potatoes from local points where the shipment volume in 1936 exceeded an arbitrarily assumed minimum of 200 cars or where the county shipments were at least 500 cars (or the counties were contiguous to large producing areas). On the basis of 500 bushels shipped per car, it may be assumed for computation purposes that for each 500 bushels of potatoes shipped, 150 bushels (30 percent) of cull and low-grade material were rejected at or near the sorting point. This is a high average value, but it is exceeded in some years, varying of course with the crop, the shipping area, and the season. On such assumption a shipment of 200 carloads a year from a given point would predicate an accumulation of 30,000 bushels of low-grade material. This would seem to be a large amount of material to allow to go to waste; but, if not used for feed or starch production, such material is usually a complete loss at present. However, in considering converting this material into alcohol on the minimum basis of a 2,000-gallon alcohol plant (table 6), it must be realized that 30,000 bushels constitute only about 3.5 percent of the annual requirement for such minimum operation. If 25 to 30 shipping points of this same magnitude were located within reasonable haul of a central alcohol plant, the idea might be practicable. On the above assumptions, about 5,800 cars of potatoes would have to come from the area covered by this minimum-size plant. The data in table 8 show that only about three locations in the country exceeded such a requirement, although several others would approach the desired size if potatoes from contiguous counties were included or if locally raised sweetpotatoes or fruit were used to supplement the potato supply. The 30,000 bushels at one shipping point would yield only about 21,000 gallons of alcohol, which could be produced in a plant of only 175 gallons daily capacity in 4 months' operation. Obviously, supplementary raw materials would be required, even for such a small plant.

TABLE 8.—*Shipments of potatoes from local points in 1936* [1]

State	Area [2]	County	Shipping point	Potatoes	Sweetpotatoes	Total carloads shipped in county
				Carloads	*Carloads*	
Alabama	1	Baldwin	Foley	1,007	172	3,034 potatoes.
			Loxley	1,037	84	
			Robertsdale	506		
			Summerdale	418		295 sweetpotatoes.
	1	Escambia	Atmore	407		741.
			Huxford	266		
	1	Mobile				201.
California	3	Kern	Shafter	4,859		7,245.
			Wasco	2,187		
	1	San Joaquin	Holt	553		5,108.
			Middle River	2,450		
			Stockton	1,799		
			Terminous	295		
	2	Santa Barbara	Santa Maria	379		485.
	4	Siskiyou	Tulelake	939		946.
	2	Alamosa	Alamosa	539		683.
	2	Conejos	Antonito	212		976.
			La Jara	627		
	1	Delta	Delta	244		259.
	1	Garfield	Carbondale	861		1,180.
	1	Mesa	Fruita	229		277.
Colorado	1	Montrose	Montrose	714		1,269.
			Olathe	555		
	2	Rio Grande	Del Norte	1,080		6,242.
			Monte Vista	5,162		
	2	Saguache	Center	1,933		1,933.
	3	Weld	Ault	616		3,217.
			Eaton	773		
			Gilcrest	238		
			Greeley	506		
			Lucerne	470		
			Severance	144		
Florida	2	Dade	Goulds	440		735.
	1	Flagler	Bunnell	393		399.
	1	St. Johns	Hastings	777		1,105.
Idaho	2	Bannock	Pocatello	835		862.
	2	Bingham	Aberdeen	715		4,612.
			Blackfoot	1,121		
			Firth	596		
			Shelley	1,885		
	2	Bonneville	Idaho Falls	5,071		5,582.
			Ucon	417		
	1	Canyon	Caldwell	525		1,790.
			Nampa	378		
			Parma	219		
			Wilder	496		
	1	Cassia	Burley	1,750		2,582.
			Declo	731		
	2	Fremont	Newdale	607		1,565.
			St. Anthony	849		
	1	Gooding	Gooding	431		654.
			Wendell	199		
	2	Jefferson	Rigby	609		944.
	1	Jerome	Eden	362		1,656.
			Hazelton	542		
			Jerome	752		
	2	Madison	Rexburg	263		589.
			Sugar City	219		
	1	Owyhee	Erb	320		477.
	1	Twin Falls	Buhl	1,122		5,252.
			Filer	479		
			Hansen	747		
			Kimberly	1,280		
			Murtaugh	650		
			Twin Falls	974		
Kansas	1	Douglas	Eudora	217		587.
			Lawrence	370		
	1	Jefferson				633.
		Johnson				
		Leavenworth				
		Pottawatomie				
		Shawnee				
		Wyandotte				

[1] Data taken from reports of the U. S. Bureau of Agricultural Economics on carload shipments of fruits and vegetables by States in 1936.

[2] The several producing areas in each State have been arbitrarily numbered. All counties bearing the same number are in the same or contiguous areas.

TABLE 8.—*Shipments of potatoes from local points in 1936*—Continued

State	Area	County	Shipping point	Potatoes	Sweetpotatoes	Total carloads shipped in county
				Carloads	*Carloads*	
Louisiana	1	La Fourche	Lockport	355		808.
			Thibodaux	291		
	2	Pointe Coupee	New Roads	257		321.
	2	Rapides	Alexandria	385		480.
	1	Terrebonne	Houma	483		504.
	2	St. Landry	Sunset		1,023	2,439 sweetpotatoes.
			Arnaudville		553	
	2	LaFayette			404	
	2	Acadia			176	
Maine	1	Aroostook	Ashland	815		42,753.
			Bridgewater	912		
			Caribou	4,204		
			Easton	1,699		
			Fairmount	459		
			Fort Fairfield	4,020		
			Fort Kent	1,151		
			Frenchville	759		
			Goodrich	753		
			Grand Isle	552		
			Houlton	3,476		
			Island Falls	388		
			Limestone	2,993		
			Littleton	661		
			Madawaska	312		
			Mapleton	1,120		
			Mars Hill	2,148		
			Masardis	293		
			Monticello	896		
			New Limerick	585		
			New Sweden	318		
			Oakfield	315		
			Pharir	375		
			Presque Isle	3,522		
			Robinson	505		
			St. Luce	299		
			Sherman	532		
			Smyrna Mills	405		
			Soldier Pond	305		
			Sweden	831		
			Van Buren	1,198		
			Washburn	2,317		
			West Caribou	1,052		
			Westfield	666		
			West Presque Isle	1,146		
	1	Penobscot	Corinna	339		1,871.
			Patten	404		
Maryland	1	Piscataquis	Dover-Foxcroft	261		357.
	1	Worcester	Berlin	405		1,560 potatoes.
			Pocomoke	594		188 sweetpotatoes.
Michigan	1	Wicomico				367 sweetpotatoes.
	1	Grand Traverse				519.
	1	Missaukee	McBain	203		405.
	1	Montcalm	Greenville	279		1,034.
	1	Emmet	(3)			2,400.
	1	Isabella				
	1	Leelanau				
	1	Mecosta				
	1	Osceola				
	1	Wexford				
	1	Becker				357.
Minnesota	1	Clay	Baker	292		2,875.
			Barnesville	226		
			Dilworth	233		
			Glyndon	204		
			Hawley	465		
			Moorhead	635		
			Sabin	310		
	2	Freeborn	Hollandale	764		916.
	4	Isanti	Cambridge	215		2547.
	1	Kittson	Kennedy	272		858.
	1	Marshall				241.
	3	Mille Lacs	Princeton	205		240.
	1	Norman	Ada	457		831.

[3] No large shipping points.

TABLE 8.—*Shipments of potatoes from local points in 1936*—Continued

State	Area	County	Shipping point	Potatoes	Sweetpotatoes	Total carloads shipped in county
				Carloads	*Carloads*	
Missouri	1	Polk	East Grand Forks	900		1,636.
	1	Ray	Orrick	241		503.
	1	Jackson				328.
		Clay				
Nebraska	1	Box Butte	Alliance	232		1,153.
			Hemingford	921		
	1	Dawes				308.
	1	Kimball	Kimball	423		631.
	1	Morrill	Bayard	613		625.
	1	Scotts Bluff	Gering	647		4,826.
			Haig	201		
			Henry	200		
			Lyman	664		
			Minatare	210		
			Mitchell	1,243		
			Morrill	268		
			Scottsbluff	920		
			South Mitchell	312		
	1	Sheridan				249.
New Jersey	2	Cumberland	Bridgeton			400.
	1	Mercer	Hightstown	996		2,144.
			Lawrence	243		
			Robbinsville	537		
	1	Middlesex	Cranbury	1,661		2,047.
			Jamesburg	212		
	1	Monmouth	Englishtown	333		2,242.
			Freehold	829		
			Marlboro	351		
			Tennent	391		
	2	Salem				238 potatoes. 130 sweetpotatoes.
	2	Atlantic				1,254 sweetpotatoes.
		Cumberland				
		Gloucester				
New York	1	Allegany				358.
	1	Genesee				1,304.
		Livingston				
		Monroe				
		Ontario				
		Wayne				
		Wyoming				
	1	Steuben				1,139.
	2	Suffolk	Riverhead	249		2,862.
			Calverton	211		
North Carolina	1	Beaufort	Aurora	341		1,131.
			Pinetown	222		
	2	Currituck	Shawboro	349		492.
	1	Pamlico	Grants	332		976.
			Oriental	245		
	2	Pasquotank	Elizabeth City	854		854.
	1	Wayne	Mount Olive	334		348.
North Dakota	1	Cass				409.
	1	Grand Forks	Grand Forks	268		1,088.
			Thompson	210		
	1	Pembina	Crystal	576		1,688.
			Saint Thomas	272		
			Walhalla	528		
	1	Traill				394.
	1	Walsh	Edinburg	328		3,270.
			Grafton	510		
			Hoople	989		
			Nash	336		
			Park River	502		
Oregon	1	Deschutes	Redmond	377		384.
	1	Klamath [4]	Klamath Falls	878		4,738.
			Malin	1,217		
			Merrill	2,643		
Pennsylvania	1	Lancaster				530.
South Carolina	1	Beaufort				469.
	1	Charleston	Charleston	414		1,452
			Meggett	525		
			Yonges Island	431		
Texas	1	Cameron	Brownsville	379		948.
			San Benito	198		

[4] Adjoins area 4 in California.

TABLE 8.—*Shipments of potatoes from local points in 1936*—Continued

State	Area	County	Shipping point	Potatoes	Sweetpotatoes	Total carloads shipped in county
				Carloads	*Carloads*	
Utah	1	Weber	Ogden	383		447.
Virginia	1	Accomac	Oak Hall	1,799	1,001	1,832.
	1	Norfolk	Norfolk	293		1,448.
			Norfolk Yard	352		
	1	Northampton	Cape Charles	2,543	141	4,206.
			Exmore	1,663	1,232	
	1	Princess Anne				913.
Washington	1	Kittitas	Kittitas	615		1,304.
			Thrall	427		
	1	Yakima [5]	Brownstown	408		2,367.
			Harrah	394		
			Satus	279		
			Toppenish	316		
			Wapato	254		
Wisconsin	1	Langlade	Antigo	714		1,031.
	1	Marathon	Elderon	332		596.
	1	Marinette				416.
	1	Portage	Amherst	300		1,629.
			Amherst Junction	204		
			Arnott	203		
			Rosholt	259		
			Stevens Point	226		
	1	Waupaca	Iola	213		752.
			Waupaca	342		
Wyoming	1	Goshen	Torrington	243		685.
	1	Laramie	Pine Bluffs	331		736.
Total						181,605 [6] [7]
Total United States shipments						222,344.

[5] The following carload shipments of fruit were also made from this county: Apples, 11,690; cherries, 263 mixed fruit, 1,142; peaches, 1,333; pears, 4,164; prunes and plums, 448.
[6] Does not include sweetpotatoes.
[7] 81.6 percent of total United States shipments.

Annual accumulations of unsalable materials at such central points loom large in the local picture, and a use should certainly be found for them. But where the amounts available at any point are below the essential requirements for a minimum-capacity alcohol plant, it is cheaper to waste the material than to incur expense trying to process it into another product, unless such product can yield sufficient return. However, if sufficient quantities of suitable raw material of reasonably good grade were consistently available at a central point at a low price, the operation of an alcohol plant on a continuous basis might be considered.

The average use of potato crops in the United States during the period 1929–36 was about as follows: Sold, 64.4 percent; local seed, 10; food or feed on farms, 20.9; unfit for use, 4.7 percent.

COST OF RAISING FARM CROPS

The cost of raising crops varies in each locality. Acre yields, taxes, labor costs, rent or interest rates, and other items differ greatly between States and even between parts of the same State, in successive years. Likewise, reported costs do not always include the same charges, nor are they computed on the same relative basis. No comparable figures therefore can be given. Crop-raising costs are of greater relative importance when entire crops are raised specifically for industrial use. Such costs would have to be separately considered on the basis of each individual production item as far as surpluses, culls, byproducts, or relatively unsalable grades of any crop are con-

cerned. The price at which crop materials might be sold for alcohol production may have no relation to the cost of raising them. Such sale might merely represent additional cash return from an otherwise unsalable material, or it might represent an indirect return in the shape of an increase of price of the normal market grade by removal of the excess material from the market, or it might represent supplementary income from low-grade portions of a crop the principal expense of which has already been defrayed by the sale price of the main portion of the crop.

COST OF COLLECTING AND TRANSPORTING FARM CROPS

Freight and collection costs of raw materials would constitute a large portion of the expense in the production of motor-fuel alcohol

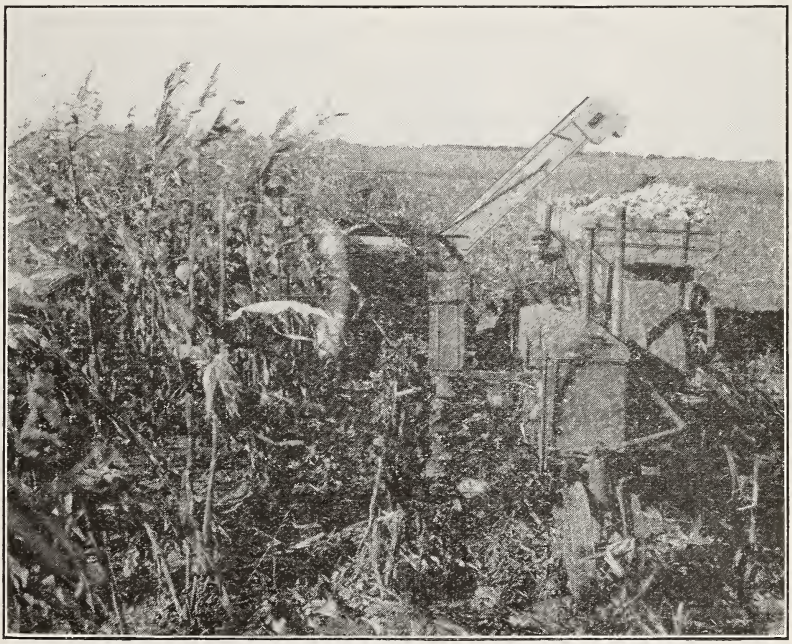


FIGURE 20.—Machine harvesting of corn.

from agricultural products. The price that the alcohol plant would be able to pay the producer for the raw material would probably be low because of the limitation imposed by a low sales return on the product. And yet the raw material must bring enough return to the farmer to justify handling and collecting, and should bear a proportionate share of the crop-growing cost. It is obvious that too low a raw-material price would not justify the cost of collection, unless other factors made such collection desirable. The narrow margin necessitates therefore the absence of middlemen and the holding of transportation costs to a minimum. This predicates a short haul, bulk shipments, and the direct sale of material from farm to plant.

The location of an alcohol plant in the center of a good producing area of 10-mile radius would make available the product of about 314 square miles or 201,000 acres. Perhaps 100,000 acres might be actually planted to the crops which might be used at the plant. In the case of corn, this might suffice for three alcohol plants of 10,000 gallons daily output capacity each. With trucking at perhaps 10 cents per ton-mile, a cost of 80 cents per ton would be incurred for an 8-mile haul (*25*). The average haul would be 6.6 miles. The cost of husking corn by a machine picker (fig. 20) at perhaps 8 cents a bushel might amount to $2.86 per ton, including labor (*67*).

ALCOHOL AND THE AGRICULTURAL-CROP SITUATION

The crop statistics heretofore quoted reflect the conservative expectancy of probable raw materials. Computations for a proposed alcohol-production program which are based on high yields per acre, as determined under experimental crop-raising conditions, are not likely to be realized. While such figures may perhaps apply to a limited production in a given area, they will not hold for the entire country.

A program of alcohol production based on the fluctuating supply of raw material provided by culls and surpluses might have more chance of success as a local, rather than as a national, industry. On this basis, there would, of course, be shortages or excesses of raw materials at various points from year to year. Plants in regions where a number of crops were available would have a probable advantage. Moreover, individually situated alcohol-processing plants would have a greater problem as to ultimate profit on the venture, because the extra expense of forcing sales of products through the adjacent region in competition with unblended fuels would have to be added to the uncertainty as to materials and costs. These difficulties would increase as more processing plants were built within an area. Furthermore, high values at present quoted for the byproducts, such as stock feed, are not likely to be maintainable under an expanded program where there would be competition between a number of producing plants. Such a status for a motor-fuel alcohol industry would not be satisfactory in the long run, but the development of the necessary crops and of production and sales organizations for a Nation-wide use of a standard blend may require an evolution through such a partial or semilocalized production stage.

It is impossible to give any specific figures below which a given yield from a specific raw material or plant operation would be uneconomic. Each instance must be considered with reference to the respective factors involved. On the basis of past commercial experience the alcohol yields per ton and per acre from various crops, shown on page 28, represent the probable range from good to very bad, with the probability that any material listed below corn in the tonnage tabulation would be near the economic borderline unless processes are improved or other advantages secured.

Establishing an alcohol plant is justified only on an expectancy of at least 20 years' operation in order that amortization may be possible without using too high a yearly depreciation percentage, so as to keep the unit cost of the product low. Extensive repairs or rebuilding or equipment additions would naturally lengthen the required amortization period. Alcohol plants cannot be constructed for safe or efficient

operation on any basis of "here today and gone tomorrow." Adequate and continued operation should be assured for a long time, and the enterprise should be sufficiently capitalized to be able to weather financial difficulties.

PRESENT RAW-MATERIAL LIMITATIONS FOR ALCOHOL PRODUCTION

Table 9 shows the crop tonnage and crop acreage required to produce a quantity of alcohol equivalent to 10 percent of the gasoline consumed in the United States in 1930 and 1935. The data in this table show that corn is the only crop at present produced in excess of such requirements. The entire wheat crop of 1935 does not quite equal the amount required to produce the necessary quantity of alcohol, and the other crops supply only minor percentages of such requirements; in fact, all these other crops taken together would total less than the required amount.

TABLE 9.—*Raw material and acreage required to produce a quantity of alcohol equivalent to 10 percent of the gasoline consumed in the United States in 1930 and 1935* [1]

RAW MATERIAL

Raw material	Unit	Amount of raw material required to make 1,000 gallons of alcohol	Amount of raw material required to make alcohol equal to 10 percent of the gasoline consumed [2] in—		Amount of raw material produced in the entire United States in—	
			1930	1935	1930	1935 [3]
Barley	Bushels	525	774, 443, 775	900, 917, 850	303, 752, 000	292, 249, 000
Corn	do	426	628, 405, 806	731, 030, 484	2, 065, 273, 000	2, 202, 852, 000
Grain sorghum [4]	do	400	590, 052, 400	686, 413, 600	37, 203, 000	57, 045, 000
Rice, rough	do	540	796, 570, 740	926, 658, 360	44, 923, 000	38, 452, 000
Rye	do	455	671, 184, 605	780, 795, 470	46, 275, 000	57, 936, 000
Wheat	do	384	566, 450, 304	658, 957, 056	889, 702, 000	603, 199, 000
Jerusalem-artichokes	Tons	50	73, 756, 550	85, 801, 700		
Potatoes	Bushels	1, 430	2, 109, 437, 330	2, 453, 928, 620	332, 693, 000	356, 406, 000
Sweetpotatoes	do	1, 000	1, 475, 131, 000	1, 716, 034, 000	53, 117, 000	69, 853, 000
Sugar beets	Tons	45. 2	66, 675, 921	77, 564, 737	9, 199, 000	7, 984, 000

ACREAGE

Raw material	Assumed yields per acre	Acreage required to produce 1,000 gallons of alcohol	Acreage required to produce alcohol equal to 10 percent of the gasoline consumed [2] in—		Acreage actually harvested in the entire United States in—	
			1930	1935	1930	1935
		Acres	*Acres*	*Acres*	*Acres*	*Acres*
Barley	22.50 bushels	23. 3	34, 370, 552	39, 983, 592	12, 666, 000	12, 858, 000
Corn	45.00 bushels	9. 5	14, 013, 744	16, 302, 323	101, 083, 000	92, 727, 000
Grain sorghum [4]	27.40 bushels	14. 6	21, 536, 913	25, 054, 096	3, 449 000	4, 878, 000
Rice, rough	50.00 bushels	10. 8	15, 931, 415	18, 533, 167	961, 000	784, 000
Rye	16.40 bushels	27. 7	40, 861, 129	47, 534, 142	3, 612, 000	4, 063, 000
Wheat	22.80 bushels	16. 8	24, 782, 201	28, 829, 371	62, 661, 000	49, 826, 000
Jerusalem-artichokes	9.00 tons	5. 55	8, 186, 977	9, 523, 989		
Potatoes	195.0 bushels	7. 35	10, 842, 213	12, 612, 850	3, 030, 000	3, 271, 000
Sweetpotatoes	155.0 bushels	6. 5	9, 588, 352	11, 071, 187	649, 000	778. 000
Sugar beets	13.00 tons	3. 48	5, 133, 456	5, 971, 798	783, 000	771, 000

[1] All computations are based on data in table 2.

[2] The total gasoline consumption in the United States was 14,751,310,000 gallons in 1930 and 17,160,340,000 gallons in 1935. These data were taken from Bureau of Public Roads statistics.

[3] Preliminary estimates (*76*).

[4] Figures include only sorghum used for grain purposes. If the entire crop were considered, the production for 1935 would be 103,494,000 bushels.

TABLE 9.—*Raw material and acreage required to produce a quantity of alcohol equivalent to 10 percent of the gasoline consumed in the United States in 1930 and 1935*—Continued

ALCOHOL OBTAINABLE VERSUS REQUIREMENT

Raw material	Alcohol obtainable from 1935 crop	Percentage of requirement for a national 10-percent blend obtainable from 1935 crop [5]	Percentage of 1935 crop required for a 10-per cent blend [5]
	Gallons		
Barley	555,273,100	32.30	308.0
Corn	5,176,702,200	301.00	33.2
Grain sorghum [4]	136,908,000	8.41	1,205.0
Rice, rough	71,207,000	4.15	2,410.0
Rye	127,459,200	7.43	1,350.0
Wheat	1,568,317,400	91.60	109.3
Jerusalem-artichokes			
Potatoes	249,484,200	14.50	687.0
Sweetpotatoes	69,853,000	4.07	2,455.0
Sugar beets	176,446,400	10.30	974.0

[4] Figures include only sorghum used for grain purposes. If entire crop were considered the production for 1935 would be 103,494,000 bushels.

[5] Assuming that the total amount would be produced from one crop.

If the entire 1935 production of the 10 principal carbohydrate crops listed in table 9 were converted into alcohol, a total of 8,131,650,500 gallons might be obtained, equivalent to 47.4 percent of the gasoline used during that year. But this would leave the Nation without food.

Considering that probably only from 5 to 10 percent of any present crop usually would be available over and above normal market requirements without introducing price disturbances and considering further that, as a rule, perhaps only 10 to 15 percent of any crop would constitute an available surplus even in good years, some idea can be gained as to the inadequacy of present crops for the production of motor-fuel alcohol in very great amounts. It seems evident that the production of alcohol from agricultural materials in quantities sufficient to have a significant bearing on petroleum conservation would necessitate increased crop production.

It is obvious that a motor-fuel alcohol program based only on the utilization of culls and wastes (5 to 15 percent of present crops) would necessarily be even more limited, and such a program would suffer from periodic shortages or excesses of raw material. Production would have to be confined to local areas and intermittent operation, and the plants would have to be relatively small, with probable consequent loss of economy in operation. Such a crop-byproduct-utilization industry would be difficult to maintain. Moreover, the overhead costs would be so high relatively that the system might be impracticable from the standpoint of low-price alcohol.

If it is assumed that 15 percent of each carbohydrate crop might be used as raw material for alcohol without affecting the market price or supply of food, the quantities shown in table 10 may be considered as available. Actually, only a portion of these amounts would ever be likely to reach an alcohol plant, because of the low price that would probably be paid for such materials and the high cost of collecting and transporting due to the distribution of the crops over great areas. Fifteen percent of the 25 carbohydrate crops shown in table 10 would

yield probably 1,444,634,900 gallons of alcohol, which is sufficient to make an 8.5-percent blend of the quantity of gasoline consumed in 1935, or a 6.8-percent blend of the 1937 consumption (21,208,977,000 gallons).[7]

TABLE 10.—*Quantity of alcohol obtainable from 15 percent of the various crops produced in the United States in 1935*

Material	Unit	Total crop (76)	15 percent of crop	Quantity of 99.5-percent alcohol obtainable [1]
				Gallons
Apples	Bushel	167, 283, 000	25, 000, 000	8, 750, 000
Apricots	Ton	216, 000	32, 400	440, 000
Barley	Bushel	285, 774, 000	42, 750, 000	81, 250, 000
Buckwheat	do	8, 332, 000	1, 250, 000	2, 620, 000
Carrots	do	13, 138, 000	1, 965, 000	491, 000
Corn	do	2, 303, 747, 000	345, 500, 000	777, 560, 000
Dates, dry	Ton	3, 230	470	37, 100
Figs	do	35, 790	5, 375	113, 000
Grain sorghum	Bushel	54, 634, 000	8, 200, 000	18, 200, 000
Grapes	Ton	2, 454, 615	368, 000	5, 550, 000
Oats	Bushel	1, 194, 902, 000	179, 000, 000	182, 500, 000
Peaches	do	52, 808, 000	7, 920, 000	2, 220, 000
Pears	do	22, 035, 000	3, 300, 000	955, 800
Plums	Ton	124, 540	18, 700	204, 000
Potatoes	Bushel	386, 380, 000	58, 000, 000	40, 000, 000
Sweetpotatoes (including yams)	do	83, 128, 000	12, 490, 000	11, 740, 000
Rice, rough	do	38, 784, 000	5, 820, 000	10, 420, 000
Rye	do	58, 597, 000	8, 800, 000	19, 350, 000
Sorgo sirup	Gallon	13, 350, 000	2, 000, 000	820, 000
Sugar beets	Ton	7, 908, 000	1, 185, 000	26, 200, 000
Sugarcane (for sugar)	do	4, 573, 000	685, 000	10, 400, 000
Sugarcane (for sirup)	Gallon	25, 982, 000	3, 900, 000	1, 600, 000
Sugarcane molasses, blackstrap	do	28, 906, 000	4, 300, 000	1, 774, 000
Wheat	Bushel	626, 344, 000	94, 000, 000	241, 500, 000
Total				1, 444, 634, 900

[1] Based on the average fermentable content of the respective materials as shown in table 2.

If culls and byproducts amounting to approximately 5 percent of the normal crops were available for processing into alcohol each year, a standardized national blend containing 2½ percent of alcohol might be possible on the basis of present crop production. However, owing to the uncertainty regarding the crop culls, byproducts, and surpluses that would be available in successive years, and because of the wide geographical distribution of such material, it is difficult to estimate the actual amount of alcohol that could be made for this purpose, and consequently the blend-percentage possible with present crops on a national basis is open to question. The same statement applies to surplus crops or to a combination of surplus and culls. A 5-percent national blend would probably be the maximum.

FARM LAND

In considering the increased crops required for a national agricultural-fuel program the question arises as to the availability of the necessary farm land. Table 11 shows the farm-land acreage of the United States. In 1929, 38 percent of the farm land was in crops, 37 in pasture (exclusive of woodland pasture), 15 in woodland, and 10 percent in idle land, woodland pasture, farmsteads, lanes, and waste. It is estimated that 75 million acres of farm land should be withdrawn from arable farming (including 20 million acres of crop-

[7] Bureau of Public Roads report.

land) as submarginal. At the same time, population increases by 1960 may call for an increase of 55 million acres for food purposes, which must come from plowable pasture, draining of land at present unfit for farming, irrigation areas, cut-over timber land or woodland, and rebuilding of eroded areas (*80*). The carbohydrate food crops grown in 1936 required a total of 199,378,200 acres, which is about 59 percent of the total net cropland.

TABLE 11.—*Acreage and uses of the farm land of the United States* (*79*)

Item	1935 (Jan. 1)	1930 (Apr. 1)	1925 (Jan. 1)
Approximate land area—acres	1, 903, 216, 640	1, 903, 216, 640	1, 903, 216, 640
Proportion in farms—percent	55. 4	51. 8	48. 6
Average size of farms—acres	154. 8	156. 9	145. 1
All land in farms—do	1, 054, 515, 111	986, 771, 016	924, 319, 352
	1934	1929	1924
Cropland harvested—acres	295, 624, 176	359, 242, 091	344, 549, 267
Crop failure—do	63, 681, 777	12, 706, 583	13, 017, 949
Cropland, idle or fallow—do	56, 028, 978	41, 287, 216	33, 892, 686
Plowable pasture—do	98, 579, 038	109, 159, 914	113, 567, 498
Woodland pasture—do	108, 095, 711	85, 321, 900	76, 703, 946
Other pasture—do	311, 225, 652	269, 672, 710	217, 687, 145
Woodland, not pastured—do	77, 379, 254	64, 623, 825	67, 067, 215
All other land in farms—do	43, 900, 525	44, 756, 777	57, 833, 646
Land used for crops—do	359, 305, 953	371, 948, 674	357, 767, 216
Percentage of total farm land	34. 1	37. 7	38. 7
Land available for crops—acres	513, 913, 969	522, 395, 804	505, 027. 400
Percentage of total farm land	48. 7	52. 9	54. 6
Total pasture land—acres	517, 900, 401	464, 154, 524	407, 958, 589
Percentage of total farm land	49. 1	47. 0	44. 1
Total woodland—acres	185, 474, 965	149, 945, 725	143, 771, 165
Percentage of total farm land	17. 6	15. 2	15. 6

On the basis of the data in the preceding tables, the production of alcohol from farm crops in amounts equivalent to 10 percent of the motor fuel used in 1936 would require the acreage shown in table 12.

TABLE 12.—*Acreage required to produce raw material for a quantity of alcohol equivalent to 10 percent of the motor fuel used in 1936* [1]

Material	Acreage	Percentage of total land usually in crops
Sugar beets	5, 972, 000	1. 44
Corn	16, 302, 000	3. 96
Wheat	28, 830, 000	7. 00
Barley	39. 984, 000	9. 64
Rye	47, 534, 000	11. 50

[1] Assuming that the total amount would be produced from one crop.
[2] 413 million acres.

It can be assumed, therefore, that in addition to the 55 million acres needed to meet future food requirements, perhaps an additional 25 million acres would be required for alcohol production, or a total increase of perhaps 23.7 percent of the net cropland (338 million acres) remaining after the retirement of submarginal land. This is apart from the land required for crops grown for any other industrial use.

INDUSTRIAL CROPS

It has been shown that any large-scale motor-fuel program would require additional crops above present normal production and that the price return on crops used as raw materials for alcohol would be low. The necessary cheap materials might be obtained from increased acreage farmed according to the usual system, whereby the usual quantities for food or feed are sold at prices normal to these markets and the lower grades are applied industrially at such prices as are securable; or, as an alternative, specific whole crops might be raised for industrial use. This alternative might perhaps assure a more definitely predictable amount, but the over-all price return on such crops might average less than in the other case, especially when food or feed prices are high. Farm costs for such items as taxes, labor, seed, fertilizer, machinery, and overhead are not likely to be reducible, and in any case must be met, but under the first alternative they may be disproportionately distributed among the various grades. Certainly no undue portion of these can be added to the low-grade material applied to alcohol production, since the motor-fuel price must remain low so as not to retard motorization expansion. In the case of crops raised specifically for industrial use, the overhead would be evenly distributed over all the units produced, and therefore such units should be produced in sufficient quantity to keep the overhead unit charges low. Raising more crops on the same acreage would mean proportionately increased costs for labor, seed, and fertilization, the last item being perhaps the principal one, but it is probable that some other costs might be reduced proportionately by money-saving changes in farm procedure and the increased use of machinery practicable with large-scale operation. Sorting and grading might be eliminated, and damaged and cull material ordinarily wasted could be collected and used with practically no additional expense. On a properly equipped farm, capital expense for machinery should not greatly increase, but the machinery would work more hours per year. Crop failures, however, would represent a heavier investment loss than under the present system.

Certain crops, such as sweetpotatoes, which in some cases are now grown on a short-season basis in order to limit the size of the individual tubers to market requirements, might be grown on a longer-season basis to increase both the size of the tubers and quantity of starch produced per acre. More efficient use of labor and equipment would also be possible with large-scale operations. On large farms there might be sufficient stalks, straw, and other wastes from an increased crop to permit the economic utilization of these materials also, thereby increasing the profit from the crop, provided the condition of the soil did not require the return of these to the land. Assured industrial outlets would remove the present serious obstacle to successful farming, that is, an unsalable surplus which remains as a penalty on the farmer's industry and a hindrance to future operations. Growing crops for industrial purposes would hardly be practicable on small diversified farms. It probably would be restricted to the best areas and climates and would be largely a machine operation. But the necessary market outlets, such as that for alcohol as a motor fuel, must be brought into existence before an industrial-crop development can be successfully realized.

Experimentation has indicated that the average production of various crops might be considerably increased by improved farming methods. New developments with hybrid corn, sweetpotatoes, and other crops have shown that it is possible to increase acre production of these raw materials, at least in the more suitable areas.

Increased crop production should result in increased employment of labor and increased demand for seed, fertilizer, farm machinery, etc. Exact estimates of the amounts involved are impossible; some estimates in the past have probably been overoptimistic. A motor-fuel alcohol industry would undoubtedly stimulate crop raising, however, if attractive prices could be paid for the raw material.

Alcohol production in large amounts would mean a corresponding increase in the available quantities of byproduct stock feed. In Germany production of farm alcohol has been directly associated with dairy and stock farming, and such an arrangement would probably have to be used in this country to keep the cost of the alcohol fuel low. Stock farming is limited, however, by the market for the products, and any great increase in this industry to absorb the byproduct feed would probably not be practical. Any crop expansion would have to be integrated with the present agricultural situation. Assuming that present livestock could not be increased without disorganizing the animal-product market, then the maximum industrial production of corn, for example, for alcohol motor-fuel production might be visualized somewhat as follows.

At present about 2 billion bushels of the approximately 2,500 million bushels of corn produced annually is used for stock feeding. The remainder is used for human food, in industry, exported, etc., and may be ignored for the purpose of this computation. Assuming that one-quarter of the corn used for alcohol production is regained as stock feed and that this feed constitutes 50 percent of the diet of an animal (a questionably high percentage), it has been argued that the 2 billion bushels of corn now used for stock feed might be replaced by 1 billion bushels of corn and 1 billion bushels of corn residue, the latter being the byproduct from an original 4 billion bushels of corn used for the production of alcohol. These 4 billion bushels would yield 10 billion gallons of alcohol, or over four times the present national requirement for a 10-percent alcohol blend. If the yield per acre of the entire 100 million acres used for corn in the United States (in round numbers) were doubled, that is, increased to an average of 50 bushels, this increase of 3 billion bushels of corn might conceivably be produced with perhaps a 10-percent increase in acreage. The practicability of such increase in acre production is, however, very doubtful. With present acre yields, a total of 220 million acres would be necessary to produce the required crops, representing an impractical increase of 120 million acres, thus more than doubling our corn acreage. Growing industrial raw materials on such a scale would evidently require acreages probably not available.

To restate the situation in a computation more nearly representing the actual possibilities, if we assume a requirement of 2,500 million gallons of alcohol for a national 10-percent blend program, 1 billion bushels of corn would be necessary as the raw material, from which 250 million bushels of byproduct stock feed would be available. Assuming that the distillers' grains would have the same relative feed value as corn and would constitute about 12.5 percent of the diet,

a total crop increase of 750 million bushels of corn would be required to maintain present stock-feed requirements and provide this alcohol. This would necessitate either an increase of 30 million acres, with present yields, or a 30-percent increase in yield on the present acreage. A compromise increase of both acreage and yield would probably result.

TECHNICAL ASPECTS

PRODUCTION OF INDUSTRIAL ALCOHOL

ALCOHOL TAXES AND REGULATIONS

The principle of taxation of spiritous liquors has descended from old English law. Originally the tax may have had a relation to the intoxicating qualities of the ethyl alcohol present in such liquors when used as a beverage, the penalization constituting a source of revenue to the Government. Under its constitutional authority, the first Congress passed revenue laws in 1790, in which a tax on certain spiritous liquors was imposed. The law has been altered many times and was extensively rewritten in 1864–67. Originally the law imposed a tax on liquor only, but when alcohol began to be produced separately interpretation of the law was broadened to include it, probably because of the possibility of reverting the alcohol to beverage purposes. Under the law the tax on alcohol attaches at the moment the alcohol comes into existence as such, regardless of how it is formed or produced, its state of dilution or contamination, or subsequent use or transferal. Manufacture or possession of untaxed alcohol in any form is a criminal offense when the Government is thereby illegally deprived of revenue.

With the expanding industrialization of the country and the enlarging field of usefulness of relatively pure ethyl alcohol as a solvent, chemical agent, or proprietary medium for material formulas, this tax constituted a serious handicap in many instances. In 1906 an industrial-alcohol law was passed whereby the Commissioner of Internal Revenue was empowered to remit the tax on alcohol upon conclusive evidence that such alcohol was intended only for industrial use and had been safeguarded from entrance into beverage channels, the entire procedure being a matter of formal regulation. Subsequent changes and amendments due to the passage and subsequent voiding of the eighteenth amendment to the Constitution have resulted in the creation of the Federal Alcohol Administration, empowered to control the distribution of alcoholic beverage (distilled spirits, wines, beers, etc.), and of the Alcohol Tax Unit of the Bureau of Internal Revenue, which administers the beverage and industrial-alcohol production control under the Treasury Department regulations. In most instances safeguarding against subsequent illegal use of untaxed industrial alcohol for beverage purposes is attempted by the addition of extraneous substances which do not render the alcohol unfit for the proposed specific industrial use but which do destroy potability more or less permanently. This is called denaturation, and the product is known as "completely" or "specially" denatured alcohol, depending on the degree of such contamination. All denaturing formulas are fixed by regulation.

Plants manufacturing ethyl alcohol are called distilleries when making alcoholic beverages and industrial alcohol plants when pro-

ducing beverage alcohol or industrial alcohol. In either case a plant can operate only under an official permit, which is granted only when all phases of the operation, such as ownership, process methods, equipment, and product distribution, are disclosed to the Government. The Treasury Department assigns officers to each plant having a permit to operate, who supervise the entire manufacturing operation and keep records of raw materials used and alcohol recovered. The alcohol, as produced, must be stored in bonded warehouses, which may be on the premises, the keys for which are held by the Government.[8] The denaturing of the tax-free industrial alcohol and all shipments of pure or denatured alcohol and all removals or transfers of alcohol from industrial-alcohol plant, bonded warehouse, or denaturing plant, are supervised by the Government officer. Separate permits and bonds are required for alcohol-plant, bonded-warehouse, and denaturing-plant operations (unless located on the same premises as a continuous or integral whole), since these are considered as separate and independent operations. In the case of continuous operation, however, they may be covered by one blanket bond.

Plans for an industrial-alcohol operation must be approved by the Alcohol Tax Unit, and must show the location of grounds, buildings and building construction, equipment, valves and pipe lines, storage tanks, raw-material bins, the denaturing plant, and the bonded warehouse. All other essential details, including a complete statement of the ownership of the plant, must be filed.

The present regulations and control procedures are intended to prevent possible illegal use of untaxed alcohol as a beverage or the changing of such alcohol to a form that might be used as a beverage, which use would represent a loss of revenue to the Government. The bonds required by the Treasury Department are intended to assure the Government against tax losses from illegal diversion. In case of loss of alcohol through accident or process failure, the manufacturer is legally liable to the Government for the tax on the alcohol lost (besides losing the alcohol) unless the circumstances can be satisfactorily explained, in which case the tax may be remitted by the Treasury authorities. Government officers must be afforded entry at all times and a suitable office maintained for their use, and complete records must be kept showing the purchase and use of raw materials and the yields from the process, transfer of the finished product to the bonded warehouse, transfer of the finished alcohol from the bonded warehouse to the denaturing plant, and the disposal of the alcohol, regardless of grade. At present industrial alcohol can only be sold in pure form, or as specially or completely denatured on the basis of standard formulas. All lots of specially denatured alcohol or of tax-free pure alcohol[9] may be sold only to customers holding Government permits to purchase, and tank-car quantities of completely denatured alcohol may be purchased only with the knowledge and approval of the Alcohol Tax Unit.

INDUSTRIAL ALCOHOL DEFINED

The term "industrial alcohol" implies the industrial use of ethyl alcohol (commonly called grain alcohol). Industrial alcohol may be used either in pure form (for scientific or Government use only) or in

[8] In a continuous plant, transferals of alcohol may be made directly from plant to denaturing plant without transferal to bonded warehouse.

[9] Pure alcohol on which the tax has been paid can be purchased at any time without Federal restriction.

mixtures with other alcohols or denaturing agents. In the latter case it is known as denatured alcohol, and when thus rendered unfit for internal human consumption in accordance with the regulations of the Bureau of Internal Revenue, is free from tax, as distinguished from alcohol for beverage use, which is taxed. Pure alcohol when used for hospital or scientific purposes is also free from tax but bears a tax when used for pharmaceutical purposes or for beverage spirits (so-called neutral spirits).

The term "distilled spirits" refers to beverage use of pure or diluted solutions of ethyl alcohol and water. Beverage or "potable" spirits are not included in the term "industrial alcohol." Whisky, brandy, and rum, for example, while consisting mainly of ethyl alcohol and water, contain in addition small quantities of congeneric substances which impart characteristic flavors and bouquets lacking in mixtures of pure alcohol and water. In order to govern the composition and content of these congeneric substances in alcohol intended for human consumption, care in the selection of raw materials and close control over the various steps in the process of manufacture are more essential than in the production of alcohol for most industrial purposes. The manufacture of alcohol for some industrial uses, however, also requires careful supervision over raw materials, manufacturing processes, and denaturing agents, in order to secure a product of mild or pleasing odor.

The manufacture of completely denatured alcohol frequently furnishes an outlet for certain refinery distillates which accumulate in the production of pure spirits but are unsuitable for pure-spirits purposes because of odor or taste and yet cannot easily or economically be re-refined under existing regulations. Such off-grade alcohol can sometimes be used in special denaturing formulas, but usually special denaturing formulas require the use of fairly high-grade spirits. Because of the usual percentage of off-grade alcohol normally produced in the alcohol-refining operation, a certain annual basic production of completely denatured alcohol is to be expected. If met by dull market conditions, this may indirectly affect the market price and refinery output. A considerable amount of such alcohol is marketed as an antifreeze solution; consequently, a mild winter and limited sale may cause stocks to accumulate, possibly limiting operation during the subsequent period.

Regardless of subsequent grade or use, all industrial alcohol is produced in practically pure form, usually at about 95-percent concentration. The taste and odor of different runs or different fractions vary, and the best material may be selected for pure-spirits purposes (as far as the market will allow), and the poorer grade used for purposes for which odor is of less importance.

SOURCES OF ETHYL ALCOHOL

Ethyl alcohol may be derived from four classes of raw materials: (1) Saccharine materials (sugar beets, molasses, sugarcane, etc.); (2) starchy materials (grains, potatoes, etc.); (3) cellulosic materials (wood, sulphite liquor from paper-pulp mills, etc.); (4) gases, such as ethylene, acetylene, and carbon monoxide (found in natural gas, coal gas, and waste gases from certain industrial processes such as petroleum refining, or especially prepared for the manufacture of alcohol).

In the first three cases the traditional fermentation method of alcohol production is employed. Either the raw material is one of the simpler sugars, in which case it can be fermented directly to alcohol by one of a number of varieties of yeast, or it is one of the more complex carbohydrates (starches, etc.), which must be broken down to a simpler compound (sugar) before the yeast can do its work. The normally unfermentable cellulose of wood must first be converted to fermentable sugars. The fourth case, which is one of chemical synthesis, has attained considerable commercial importance in recent years.

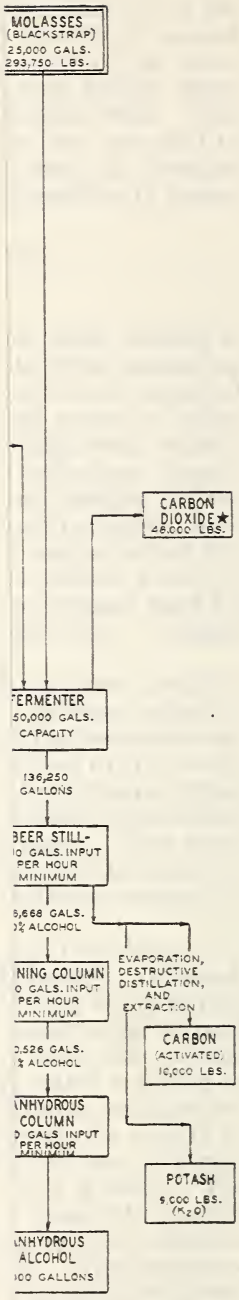
Alcohol from Saccharine Materials

sugarcane molasses

At present the cheapest source of fermentation ethyl alcohol is blackstrap sugarcane molasses, which is the waste sirup remaining after the commercial extraction of crystallized sugar from evaporated sugarcane juice. This material has been the main source of ethyl alcohol for a great many years. It has an advantage over starchy materials, such as potatoes and corn, in that its carbohydrate (sugar) is already in suitable form for transformation into alcohol by the action of yeast, whereas starch-bearing products must be treated with diastase or dilute acids to convert the starch into sugar before fermentation can take place. The actual commercial yield is about 90 percent of the theoretical. Most of the blackstrap molasses used for alcohol manufacture in this country is imported from Cuba. A small amount is obtained from Puerto Rico.

For several years a considerable percentage of the molasses used for alcohol production has been so-called "high-test" molasses, which is evaporated raw sugarcane juice from which no sugar has been removed and in which the cane sugar has been largely hydrolyzed to glucose by inversion with acid. This sirup is being produced by Cuban or other growers in an effort to keep plantations running in the face of restricted United States import quotas on crystallized cane sugar. This sirup may contain as much as 78 percent of total sugars (about half glucose), as compared with 50 to 55 percent of sugars, principally sucrose, in ordinary blackstrap molasses.

Because no preliminary grinding and conveying machinery and supplemental feed-recovery equipment are ordinarily required, molasses-conversion plants are usually simpler in design and first cost than grain plants. The general process for manufacturing alcohol from blackstrap molasses is as follows: Molasses from the storage tanks is pumped to mixers, where sufficient warm water is added to reduce the sugar content to about 12 percent (a dilution of approximately 1:4 or 4½), and sulphuric acid is added to bring the acidity to the optimum. If the molasses is deficient in available nitrogen, ammonium salts are also added to stimulate yeast growth. The mash is warmed to about 77° to 80° F. After being thoroughly mixed, it is pumped to the fermenting vats (shown in cover illustration), where a large quantity of active yeast is added. The fermentation starts immediately and is complete in 28 to perhaps 50 hours, depending on the temperature. The carbon dioxide produced is usually allowed to escape into the air, though it may be recovered by compression or liquefaction for distribution in cylinders or as solid


MOLASSES
(BLACKSTRAP)
25,000 GALS.
293,750 LBS.
CARBON DIOXIDE★
46,000 LBS.
FERMENTER
50,000 GALS.
CAPACITY
136,250
GALLONS
BEER STILL-
10 GALS. INPUT
PER HOUR
MINIMUM
8,668 GALS.
% ALCOHOL
EVAPORATION, DESTRUCTIVE DISTILLATION, AND EXTRACTION
NING COLUMN
0 GALS. INPUT
PER HOUR
MINIMUM
CARBON
(ACTIVATED)
10,000 LBS.
0,526 GALS.
% ALCOHOL
NHYDROUS
COLUMN
0 GALS INPUT
PER HOUR
MINIMUM
POTASH
9,000 LBS.
(K2O)
NHYDROUS
ALCOHOL
00 GALLONS

carbon dioxide if a commercial demand for it exists. When the fermentation is complete, the fermented liquor or "beer," as it is usually called, is pumped to stills and separated into "high wines" (containing about 60 to 90 percent of alcohol, depending on the column design), "low wines" (weak head and tail fractions from the columns, which are re-run in succeeding batches), and "slop," which is usually discarded. The slop is sometimes concentrated and used as a core binder in foundries, as a briquet adhesive, or dried and calcined to yield potash fertilizer. A second distillation of the high wines gives 95-percent alcohol and fusel oil, which is a mixture of alcohols of higher molecular weight (amyl, isobutyl, etc.). The 95-percent alcohol may be denatured and sold as such, or, as shown later, it may be approximately dehydrated to yield alcohol of 99.5-percent concentration. In refineries equipped for continuous distillation, these several stages may be accomplished in one continuous operation, thereby economizing steam.

In figure 21 the conventional alcohol process is schematically depicted. The different steps required for different raw materials as well as the daily requirements of each are shown.[10]

Since the greater proportion of the molasses raw material is imported, alcohol plants are more economically located on harbors permitting direct unloading of molasses from the steamer to storage tanks, thus avoiding inland freight costs. There is no standard cost for alcohol production, since no two plants are exactly alike in process, equipment, or location. An older plant of large capacity, which has been largely amortized and uses a uniform raw material to produce denatured alcohol of only a few formulas at 95-percent concentration for tank-car shipment, has a cost advantage over a plant carrying out a more complex operation. Sources of waste steam, cheap water, and cheap fuel, and the use of modern efficient equipment and automatic devices to reduce labor costs result in further economies. Recovery of potash or carbon dioxide byproducts, in addition to fusel oil, would further reduce the net cost per gallon provided that there were market outlets for these materials. Table 13 shows the probable cost for the production of 95-percent alcohol, without carbon dioxide or potash recovery.

[10] The benzol dehydration process is taken for illustration, since this is the method most used at present

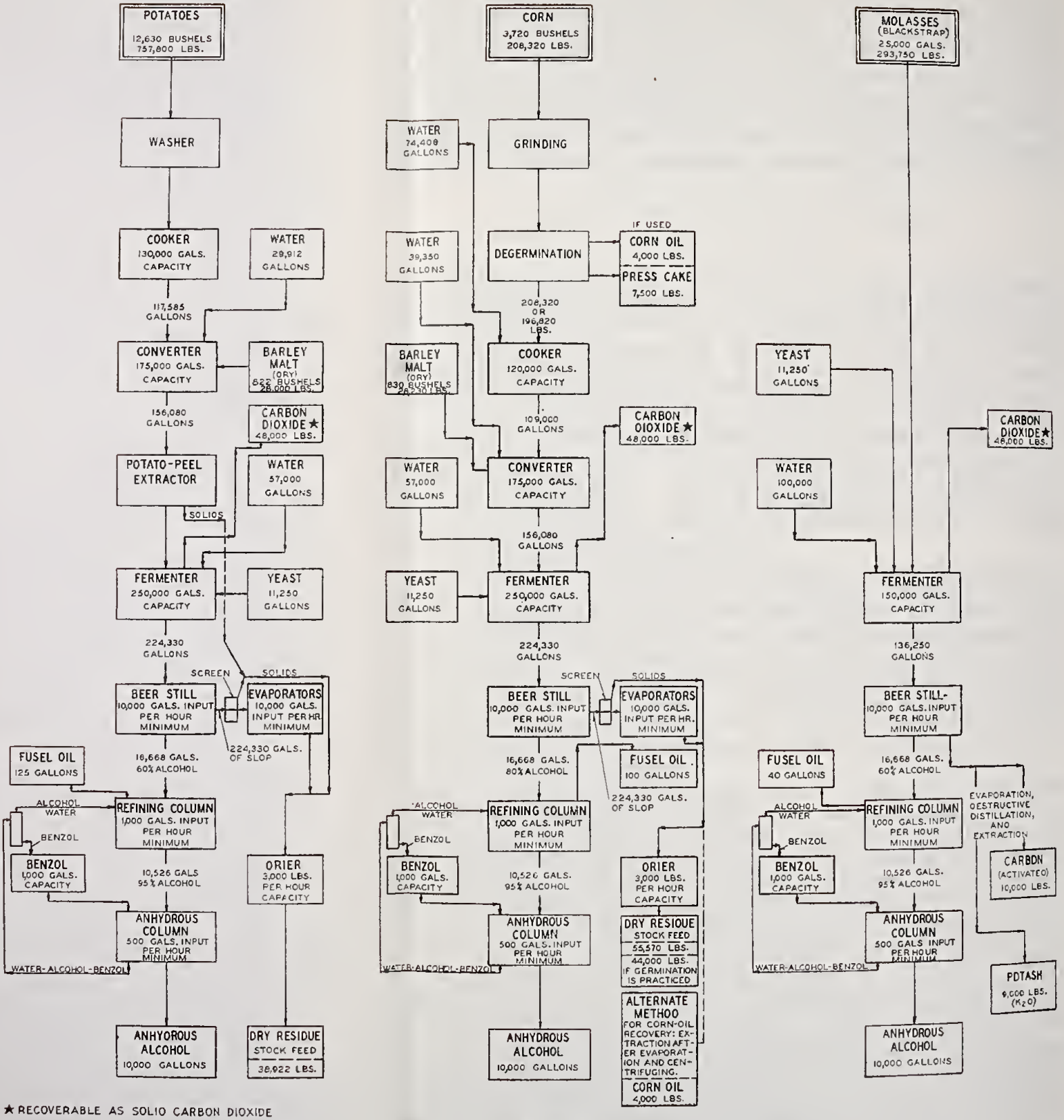


FIGURE 21.—Conventional alcohol process.

TABLE 13.—*Cost of producing alcohol from molasses*

[Per gallon]

Item	Low	Average	High
Blackstrap molasses at $0.05 per gallon (2.3 to 2.7 gallons of raw material per gallon of alcohol)	$0.115	$0.125	$0.135
Conversion cost [1] (labor, steam, chemicals, water and power, interest, depreciation, taxes, and insurance). (Credit deducted for fusel-oil byproduct.)	.035	.055	.075
Cost of 95-percent bulk alcohol in tanks	.150	.180	.210
Denaturing cost	.020	.025	.030
Sales cost, freight, and profit	.060	.075	.090
Total cost of 95-percent denatured alcohol, unpackaged (tank cars)	.230	.280	.330
Additional cost, with molasses at $0.06 per gallon	.023	.025	.027
Additional cost of producing "anhydrous" grade	.02	.025	.030
Packaging	.04	.045	.060

[1] Recent figures for a molasses plant using latest automatic equipment to save labor are:

	Cents per gallon
Labor	0.64
Steam	.98
Current	.042
Water	.064
Supplies	.075
Laboratory	.107
Chemicals	.026
Subtotal	1.934
Supervision	.50
Interest (6 percent on $250,000)	.45
Depreciation (6 percent on $250,000)	.45
Taxes and insurance	.35
Subtotal	1.75
Total	3.684

TOTAL MOLASSES SUPPLY

Since molasses is usually available in excess of normal industrial-alcohol market needs, it is a potential competitor of agricultural products as a source of motor-fuel alcohol. An estimate should be made, therefore, of the quantities of alcohol that might be obtainable from this source, as well as of the probable effect of such use on the similar employment of farm crops.

World production of sugarcane molasses for the season 1934–35 is shown in table 14. The amount of molasses shown in this table

TABLE 14.—*World production of sugarcane molasses in the season of 1934–35*

Source	Blackstrap molasses	High-test molasses
	Gallons	*Gallons*
Puerto Rico	28,000,000	39,000,000
Santo Domingo	21,000,000	
Cuba	131,000,000	57,000,000
Philippine Islands	23,800,000	15,000,000
Hawaii	45,000,000	
Haiti	1,900,000	
United States	41,000,000 [1] 15,000,000	
Total	306,700,000	[2] 111,000,000

[1] From sugar beets. Quantity reaching market.
[2] Equivalent to about 150,000,000 gallons of blackstrap molasses.

would produce about 198,600,000 wine gallons of alcohol, assuming the entire world supply were thus used. In 1935 about 81,300,000 gallons of industrial alcohol was produced in the United States (tables 15 and 16) from a portion of this molasses supply. An additional 117,300,000 gallons of alcohol might have been obtainable from the remainder. However, in the same year molasses was used for other purposes as follows (*2*):

	Gallons
Consumed in country (foreign) of origin	84, 217, 000
Used in United States for cattle feed	70, 000, 000
Used in United States for yeast and miscellaneous purposes	40, 000, 000
Total	194, 217, 000
Net available balance [1] (in terms of blackstrap)	262, 483, 000

[1] Exclusive of carry-over stocks.

Since about 240,000,000 gallons (*2*) of this available balance of blackstrap molasses was sold in the United States in 1935 for eventual use in the production of beverage and industrial alcohol, a residual amount of only around 22 million gallons of molasses is indicated. It is evident that the quantity of alcohol producible from this residual amount over a period of years would be comparatively small. Use of the excess molasses, however, would undoubtedly bring about price increases and some readjustment of the molasses market.

OTHER SACCHARINE MATERIALS

In France the sugar beet constitutes one of the most important sources of alcohol, but in the United States alcohol is not made directly from beets. A small quantity of beet molasses, obtained as a byproduct in the manufacture of beet sugar, has been used for the production of alcohol, but the amount was negligible as compared with the quantity of blackstrap molasses from sugarcane which is so used. Under certain conditions in the world sugar markets, it may perhaps be economically feasible to produce industrial alcohol by the direct fermentation of sugarcane juice. Alcohol has also been produced very cheaply from the nipa palm (*Nipa fruticans*) and similar sources.

Alcohol From Starchy Materials

CEREALS

The principal starchy materials suitable for alcohol production are (1) the cereals (corn, oats, grain sorghum, rye, rice, barley, and wheat), (2) potatoes, (3) sweetpotatoes, and (4) Jerusalem-artichokes (girasol)

Corn, our most abundant cereal, is now used to some extent in the manufacture of industrial alcohol, but such use is somewhat limited by the slightly higher cost of alcohol from corn in comparison with alcohol from cheaper materials. Corn alcohol is more generally used for beverage purposes, although in the manufacture of perfume and other special industrial products corn is frequently specified as a source of the alcohol because of the usually superior odor and taste. Wheat, rye, oats, and other cereals usually command relatively higher prices as foodstuffs, which militates against their use as raw materials for alcohol, except for beverage manufacture. They are used primarily for the production of whisky and beer. Barley in the form of

malt is employed rather extensively as an adjunct in the conversion of starch to fermentable sugar but otherwise finds little use in the production of alcohol.

In the manufacture of alcohol from corn the first step is grinding (in some cases after the removal of the oil-bearing germ). Figure 22 shows typical grain mills. Some water is added, and the ground material is heated with steam under pressure (fig. 23), to gelatinize the starch. The resulting softened and disintegrated material is blown to a vat, cooled to the mashing temperature (near 140° F.), and saccharified, that is, the starch is converted to sugar, usually by the action of malt. The malt commonly used is germinated barley, which contains the malt enzyme, diastase, by means of which the saccharification is accomplished. This is the procedure usually followed in the

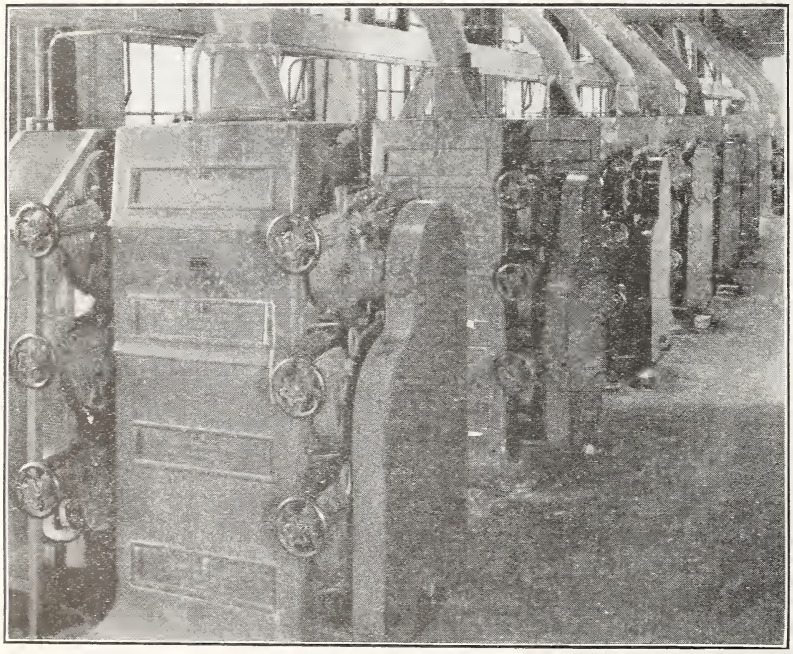


FIGURE 22.—Grain mills.

United States. It is also possible to saccharify by the use of an enzyme produced by molds (the amylo process) or by hydrolysis with dilute mineral acids. The wort, or sugar solution, however it may be obtained, is cooled (fig. 24) to the fermenting temperature of 65° to 80° F., transferred to the fermenting vats, and inoculated with yeast. The remainder of the process, except for the disposition of the slop, is in general the same as that described for the production of alcohol from molasses.

The concentrated slop or waste resulting from the fermentation of the cereal grains may be used for feeding livestock. It is rich in protein and has a high feeding value, particularly when the cereal germ has not been removed. This slop may be concentrated and fed in the

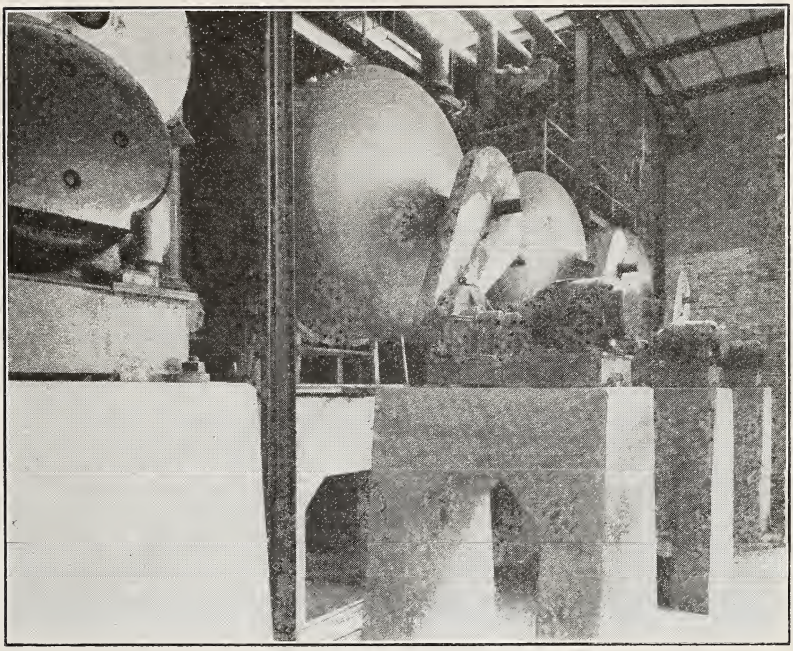


FIGURE 23.—Battery of grain cookers.

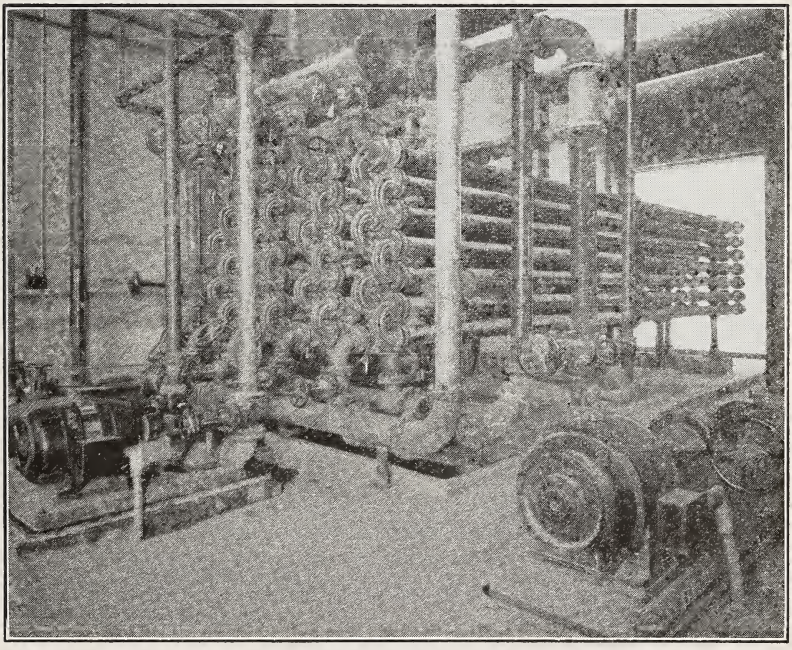


FIGURE 24.—Mash coolers.

wet form, or it may be dried and bagged, in which case it is known commercially as distillers' grains. Brewers' grains are the similar solid byproducts from beer manufacture.

The cost of producing alcohol from grain is primarily dependent on the price of grain and the return from the stock feed and other byproducts. The cost in 1933 was estimated as 31.4 cents per gallon of anhydrous alcohol from corn at 25 cents a bushel; 43.5 cents from corn at 50 cents a bushel; and 55.7 cents from corn at 75 cents a bushel. These figures, which include distribution and profit, are based on a production of approximately 10,000 gallons of alcohol per day. On a production basis of approximately 60,000 gallons, the cost was estimated at about 4.2 cents per gallon less (*74, p. 14*). In these computations a credit for the fusel oil produced was evidently not considered. The average cost of producing grain alcohol [11] might be analyzed as follows (on recent price bases):

	Average cost in cents per gallon
Conversion cost:	
Fuel (production basis of 10,000 gallons per day for 300-day year)	1. 38
Water and power	. 50
Labor	2. 50
Interest	. 85
Depreciation	. 89
Taxes and general overhead	. 88
Chemicals and supplies	. 50
	[1] 7. 50
Raw material (corn at 50 cents a bushel; malt at $1 a bushel; 10-percent malt basis. 2.3 gallons of 95-percent alcohol produced per bushel of mixed grain)	24. 40
	31. 90
Byproduct credits for feed and fusel oil (feed at $22.50 gross per ton, making a net profit of $15. Fusel oil at 1 cent per gallon of alcohol [2])	5. 10
Cost of bulk 95-percent alcohol in tanks	26. 80
Anhydrous step	2. 0
Denaturing	2. 0
Cost of anhydrous denatured alcohol at factory	30. 80
Profit [3]	1. 2
Sales and distribution [4]	6. 0
Total cost	38. 0

[1] This value would differ somewhat in various plants, but in any particular plant would remain comparatively constant. The other costs may fluctuate widely.

[2] In production of motor-fuel alcohol, fusel oil need not be separated unless sales returns justify the operation.

[3] Alcohol production usually yields a very small unit margin of profit.

[4] Depending on plant location.

ROOTS AND TUBERS

Potatoes are very largely used for alcohol production in Germany, where they are an important agricultural crop. Special types of potatoes of high starch content have been bred for the purpose, and the technology has been developed for using this material in small plants. In Germany the manufacture and distribution of alcohol is

[11] During the last half of 1937, market quotations for alcohol in tank cars, f. o. b. the distillery, were (per gallon): CD 11 alcohol, 29 cents; SD 1 alcohol, 27 cents; SD 1 (anhydrous) alcohol, 33 cents; absolute ethyl alcohol from molasses (including tax, $4), $4.47; absolute ethyl alcohol from grain (including tax, $4), $4.92. Blackstrap molasses sold at 6½ to 7 cents a gallon.

Absolute (beverage) alcohol produced from grain has commanded 45 cents more per gallon than that made from molasses. Recently this was reduced to 25 cents. The absolute grade is rated at from 5 to 6 cents more than the 95-percent alcohol. Recently the tax on alcohol was increased 25 cents a proof gallon.

controlled by the Government, and the use of potatoes for alcohol production was originally designed mainly to benefit agriculture through the advantages derived from crop rotation and other benefits of an indirect, although important, economic character. In the United States the manufacture of alcohol from potatoes has never attained any commercial importance. It has not even been an attractive commercial venture, because corn and molasses are more abundant, more concentrated, less perishable, and relatively cheaper sources of alcohol than potatoes.

Sweetpotatoes have recently aroused much interest as a source of industrial starch. Some varieties contain 30 percent or more of fermentable matter. The culls of this crop might receive favorable consideration as a source of industrial alcohol, as the price which could be paid for them for this purpose would be about the same as that offered by starch factories. With possible crop yields of from 300 to 400 bushels an acre, sweetpotatoes may give the largest total quantity of alcohol per acre of any present crop in the United States. Sweetpotatoes, however, are difficult to store, and thus present a special handling problem. Production of alcohol from the free sugar in the waste from sweetpotato-starch factories may also become of interest.

From a technological standpoint, sweetpotatoes would probably be handled in much the same manner as other starchy crops, that is, by steaming and crushing the raw material, saccharification of the starch, and fermentation with yeast. The slop, skins, etc., might be used as cattle food. As sweetpotatoes contain a natural saccharifying enzyme, similar to that of malt, the use of malt might be unnecessary.

The Jerusalem-artichoke or wild sunflower (*Helianthus tuberosus*) has of late been receiving a great deal of attention as a possible source of industrial alcohol. Inulin, its chief carbohydrate constituent, is easily broken down into levulose, a fermentable sugar. As in the case of all other farm crops, the use of Jerusalem-artichokes for this purpose is wholly dependent on the financial return that would accrue to the farmer. At present this source does not look particularly promising. Whether cultural studies might lead to increase in yield per acre and carbohydrate content is a question yet to be decided. In its industrial aspects, the production of alcohol from Jerusalem-artichokes presents much the same features as its production from sugar beets. There is at present very little production of this crop except on experimental plots.

ANHYDROUS OR ABSOLUTE ALCOHOL

In recent years there has been an increasing demand in this country for anhydrous (water-free) alcohol for industrial uses, particularly in the lacquer and film industries. Alcohol that is to be mixed with gasoline for use as motor fuel should not contain more than a few tenths of 1 percent of water. When ordinary 95-percent alcohol is mixed with a much larger proportion of gasoline, the mixture is likely to separate into two layers at low temperatures unless certain blending agents, or mutual solvents, such as butyl alcohol, benzol, or acetone, are added. Anhydrous alcohol mixes with gasoline in all proportions and at practically all temperatures.

Commercial processes and equipment have been developed for obtaining alcohol in nearly anhydrous condition from ordinary high-

proof alcohol, or directly from fermented mash. These processes increase the total production cost of the alcohol by possibly 1 to 3 cents a gallon. Many of these processes and the essential equipment are patented, and during the life of the patents can be used only under license, with possible payment of royalties to the patent owners. They include: (1) Azeotropic distillation methods, which are dependent on the fact that when suitable organic liquids, such as benzol (benzene), trichloroethylene, or volatile mineral spirits (benzine), are mixed with high-strength alcohol during distillation, the water present, with a small proportion of the alcohol, is distilled over; the excess of the azeotropic agent then distills out, leaving the rest of the alcohol in an anhydrous state. (2) Use of anhydrous materials, such as potassium or sodium alcoholate, potassium or sodium acetate, aluminum or calcium oxides, or calcium sulphate to absorb water from a vapor mixture of alcohol and water. (3) Distillation of the alcohol under a partial vacuum.

THE INDUSTRIAL ALCOHOL INDUSTRY

In 1936 at least 37 distilling plants in the United States were licensed for producing refined ethyl alcohol for beverage-spirit or industrial-alcohol purposes, but several of these were inactive. Thirty-eight active plants were listed in 1937. At least two experimental pilot plants have also been licensed. While it is difficult to compute accurately the production capacity of these plants, the normal potential total capacity in 1936 may be estimated at about 824,915 wine gallons per day. Production capacity is usually based on fermenter capacity, but obviously any decrease of normal fermentation periods from the usual 52-hour period would increase the nominal capacity. Plant capacity may also be estimated on a distillation-column output basis, the beer-still capacity being perhaps the principal factor. Installation of additional beer columns, at an expense of $10,000 per column, or less, might change a given plant capacity tremendously without much increase in capital investment. A further difficulty in estimating basic capacity for the production of beverage or industrial alcohol lies in the fact that a plant may, and sometimes does, produce both grades, either simultaneously or first one and then the other. Moreover, under disadvantageous market conditions, plants may restrict, completely suspend, or renew operations for portions of a year.

As nearly as can be estimated, at least 7 (211,934 wine gallons per day theoretical capacity) of the 37 plants existing in 1936 were producing beverage alcohol, either entirely or in part, and at least 2 were inactive (20,000 gallons capacity). By deducting the capacity of these plants from the total theoretical capacity of all the plants, a total daily industrial alcohol production capacity of 592,981 wine gallons in 1936 is indicated. Whisky, brandy, rum, gin, and wine distilleries are not included in this estimate, although these also could produce industrial alcohol without material modification of equipment, if occasion should require. The production capacity of these distilleries is about equal to that of the total plants producing industrial alcohol, but includes almost 300 establishments.

Alcohol production in 1936 totaled 196,126,236 proof[12] gallons (or

[12] For tax purposes alcohol produced is computed in proof gallons (containing 50 percent of alcohol by volume), but denatured alcohol is computed in wine gallons (U. S. gallons), as sold.

103,224,335 wine gallons of 95-percent concentration). During the same period 24,052,532 proof gallons were sold as taxed, or pure alcohol, and 172,478,748 proof gallons were denatured. The apparent difference between production and use represents differences in inventories and losses. Of the 101,477,843 wine [12] gallons of denatured alcohol produced, 64,955,485 (64 percent) were sold as special denatured; the rest, 36,522,358 wine gallons, was sold as completely denatured. On the basis of a 300-day operating year, the 35 plants that produced alcohol in 1936 had a total production for the year of about 41.7 percent of the hypothetical capacity. The number of plants in operation from 1920 to 1937, inclusive, and the industrial alcohol produced are shown in table 15. During the prohibition period an artificial situation existed.

TABLE 15.—*Quantity of alcohol produced at industrial alcohol plants from 1920 to 1937*

Fiscal year [1]	Plants operated	Quantity produced	Fiscal year [1]	Plants operated	Quantity produced
	Number	*Proof gallons* [2]		*Number*	*Proof gallons* [2]
1920	37	18, 933, 551	1929	52	200, 832, 051
1921	70	85, 068, 776	1930	50	191, 859, 342
1922	73	79, 906, 101	1931	46	166, 014, 346
1923	76	122, 402, 850	1932	43	146, 950, 913
1924	70	135, 897, 726	1933	34	115, 609, 754
1925	71	166, 165, 518	1934	34	165, 103, 582
1926	64	202, 271, 670	1935	32	180, 645, 920
1927	62	184, 323, 017	1936	35	196, 126, 236
1928	55	169, 149, 905	1937	38	223, 181, 228

[1] Ended June 30.
[2] Proof gallons divided by 1.9 equals wine gallons of 95-percent concentration.

In 1937, 77.2 percent of the 102,202,659 wine gallons of denatured alcohol produced was used in special denatured formulas; the remainder was completely denatured.

Table 16 shows the percentage of industrial alcohol produced from the principal raw materials from 1932 to 1937.

TABLE 16.—*Percentage of total ethyl alcohol produced from different kinds of raw materials from 1932 to 1937* [1]

Raw material	1932	1933	1934	1935	1936	1937
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Molasses, blackstrap	84.76	83.00	83.40	85.49	76.15	75.73
Ethyl sulphate, synthetic	9.69	9.70	7.34	9.73	16.06	15.18
Grain	3.75	4.13	6.29	2.74	7.04	8.36
Pineapple juice			.42	.34	.32	.21
Fermented liquor			.11	.07	.03	
Corn sirup			.02		.03	
Mixtures (grain, hydrol, molasses)	.86	2.24	2.42	.60	.37	.51
Other raw materials	.94	.93				.01
Hydrol				1.03		
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1] Reports of Alcohol Tax Unit.

A second plant for the production of synthetic alcohol (shown as ethyl sulphate) was put into operation in 1936, causing the increase shown in the table. Otherwise, the relative use of corn and other

materials was not changed to any significant degree. A little alcohol was made from waste sulphite liquor in 1936.

The quantities of the principal raw materials used in the industrial alcohol industry in 1936 and 1937 are shown in table 17.

TABLE 17.—*Principal raw materials used for the production of industrial alcohol in 1936 and 1937*

Raw material		Used for alcohol production	
		1936	1937
Molasses (blackstrap and invert)	gallons	173, 385, 873	202, 631, 056
Corn [1]	pounds	141, 068, 809	198, 467, 734
Rye	do	15, 283, 715	4, 598, 838
Malt (barley)	do	23, 998, 368	29, 247, 273
Pineapple juice	gallons	6, 789, 672	3, 598, 222
Sulphite liquor	do	7, 396, 855	12, 060, 125

[1] In addition, small quantities of corn sirup and "Hydrol" were used.

EXPANSION REQUIRED FOR THE PRODUCTION OF MOTOR-FUEL ALCOHOL

To produce 2,130,000,000 gallons of motor-fuel alcohol per year (representing 10 percent of the gasoline consumed in the United States in 1937) on the basis of 300 days of operation per year, a total daily plant capacity of 7,100,000 gallons would be required. Assuming that existing industrial alcohol plants now find normal market outlets for only 42 percent of their present capacity (824,915 gallons daily), 478,450 gallons daily unused capacity would be available for the production of motor-fuel alcohol. It must be remembered, however, that in time of war or other unusual market demand, this capacity would be applied to meet the more urgent needs. In any case, an additional daily capacity of at least 6,621,550 gallons would be needed. Assuming an average daily plant capacity of 20,000 gallons, about 330 such plants would have to be built. At an investment cost of perhaps $750,000 each, this would call for a total investment of practically $250,000,000.

ILLEGAL DIVERSION OF MOTOR-FUEL ALCOHOL

The general use of alcohol as a motor-fuel ingredient presents new problems in the control of illegal diversion of alcohol because of the tendency of alcohol to separate from gasoline. In alcohol-gasoline blends, this might be caused by the presence of very small quantities of water. Such separated alcohol might then be in a partially purified form, due to selective solvent action of the gasoline on the original denatured alcohol mixture, and some attempts might be made to divert it to illegal beverage use. Denaturants, therefore, must be of such character that they will remain with the alcohol if such water separation occurs, and they should be difficult to remove by subsequent treatment. The chemical compounds that even partly conform to such denaturant specification are limited.

If motor fuels from agricultural materials are produced on a national scale, it is probable that the present control over alcohol will have to be extensively increased. Illegal recovery of alcohol from the fuel blends may constitute a problem, and a means of properly safeguarding

against misuse of the alcohol must be found. At the same time, adherence to the present conventional process for alcohol production and the application of present control regulations may increase the cost of the fuel alcohol.

At present industrial alcohol is first produced in a comparatively pure form and then intentionally contaminated before being marketed as denatured alcohol. Since the alcohol may be in a considerably impure form for motor-fuel purposes without seriously impairing its value and since such alcohol must also be produced very cheaply, initial purification with subsequent denaturation appears to be both expensive and needless. The problem might be simplified if motor-fuel alcohol could be considered and produced as a new product having no relation to industrial alcohol (on the basis of present standards) and could, therefore, be safely produced and distributed without the restrictions imposed under the existing system. Such a low-grade product might be a natural mixture of alcohols and other organic substances which at no time in its manufacture reached a stage of purity permitting its application to beverage use. Such a product should not be called alcohol but should be known by some distinctive general term.

This concept might not be practicable, however, since basically any alcohol formed in any process comes under the tax provisions. Moreover, it is doubtful whether sufficient congeners of the fermentation could be naturally evolved during the process to satisfy requirements for denaturation, so that additional substances would have to be added during the process, and these substances must be difficult to remove. The ordinary congeners usually present no removal difficulty. Substances possessing a maximum of denaturing value for this purpose are not cheaply available in the requisite quantities, and no perfect denaturant is known. As a partial approach to a practical denaturant, use of a standard denaturing formula which contains considerable wood alcohol has recently been approved specifically for alcohol motor-fuel purposes. Any alcohol illegally separated from such a blend would probably be unsafe for internal use. The manufacture and use of alcohol motor-fuel blends on a national scale would greatly increase the cost to the Government for alcohol control and regulation.

PRODUCTION OF MOTOR-FUEL ALCOHOL

FUNDAMENTAL REQUIREMENTS AND ESTIMATED COST [13]

The manufacture of ethyl alcohol from farm products for specific use as a motor fuel allows a somewhat different approach from the conventional processes now used for the production of pure ethyl alcohol, since odor and palatability are not involved. The problem is that of producing an alcohol suitable only for fuel purposes in the largest possible quantities at the lowest cost from a variety of low-grade materials. With this in mind the following basic requirements may be stipulated.

[13] The probable profits from a fermentative alcohol-producing operation, whether designed to utilize present farm wastes, surpluses, and byproducts, or entire crops, might be increased if some proportion of the resultant product were of a quality likely to command higher prices, such as beverage or special industrial grades or "antifreeze" solutions. However, the manufacture of the higher priced products would probably involve more expensive equipment or processing and higher sales-distribution costs, and at the same time affect more directly the present alcohol industry. It is therefore deemed inadvisable for consideration at present, and such possibilities are not included in this report.

Raw Materials

Raw materials for motor-fuel alcohol production should be considered from the standpoint of: (1) Relative availability and net cost of fermentable content; (2) relative yields of alcohol per ton of material; (3) relative yields of alcohol per acre; (4) quality, quantity, and salability of residues or byproducts (distillers' grains).

Raw materials may be classed as to desirability somewhat arbitrarily as primary and secondary on the basis of: (1) Available supply; (2) geographical distribution or location; (3) seasonal or highly perishable character; (4) amount of culls, off-grades, or surplus available under normal conditions; (5) availability as emergency raw materials in the event of failure of the principal material.

First consideration should be given to crops which contain the largest, cheapest, or most easily available proportion of fermentable matter or which nationally or locally usually have a high percentage of surplus or culls.

The Plant

Plants should be located on ground of suitable character, as close as possible to: (1) Adequate supplies of raw materials; (2) constant and relatively cheap sources of pure water, fuel, power, labor, building materials, and process chemicals; (3) facilities for disposal of waste; (4) railroad and truck routes (to permit rapid and cheap delivery of raw materials and finished products); (5) centers of automobile use or other sales outlets. As a rule, these plants should be situated on a navigable stream, adjacent to a fairly large city.

Because of the low price that can be obtained for the product, any alcohol-producing plant design should provide for: (1) Units of adequate yet economical size; (2) flexibility of raw materials; (3) economy in handling and processing, and the use of automatic devices where economical; (4) possibility of using other fermentations, perhaps simultaneously; (5) quantity rather than quality of product; (6) buildings designed to fit the equipment and process, rather than the contrary.

The Process

Because of the desirability of producing a very cheap and perhaps an impure product, use of the methods and equipment normally employed for producing pure spirits is advisable only when it entails no extra cost, or is justified for reasons other than character of the product. The general procedure will probably have to be modeled on the conventional process, while costs are reduced by use of short cuts, revision of equipment design, or other appropriate deviations. Since the production cost of alcohol depends on raw material, labor, fuel, capital, and overhead costs, each of these items must be held rigidly to a minimum.

Plant Design and Costs

BUILDING AND DISTILLERY EQUIPMENT

Selection of a specific plan, construction materials, and detailed building specifications would have to be governed partly by the geographic location. Frame studding and ordinary galvanized siding may be sufficient in many cases, with roofing of galvanized metal carried on open rafters. Walls and roofs which may be washed down

by steam or water are recommended. Under the action of steam or weak acid fumes, galvanized siding will spall, causing trouble. All wood interiors should be painted, and ledges where dust may accumulate should be avoided. In general all buildings should have substantial concrete floors, preferably dustproof and nonabsorbent. They should be well sloped to convenient sewer outlets and bordered by a curb or rim, on which the wood sills should be placed. This method makes it easy to keep all floor corners clean and free from sources of contamination. Fermenter houses using open-top fermenters should have ventilation down to the floor level.

Wooden fermenting tubs are cheaper than steel tubs, but they are more difficult to sterilize and more liable to leak, and there is some loss of the product by evaporation from the top. Wooden tubs should be located indoors to control contamination or other factors, and they should be covered. Steel fermenting tanks may be located outdoors if of the closed-top design. Beer wells are a convenience when the number of fermenters is limited. They should be of metal or nonabsorbent concrete, well sloped, and easily accessible for washing and sterilization.

The installation of convenient hoist-supporting beams over certain portions of apparatus (such as columns) is recommended to facilitate erection and dismantling. Walls and floors for any structure should be ample to sustain all the weight likely to bear thereon. Buildings should preferably be fireproof and well ventilated, and boilers or open flames must be kept at a safe distance from, and to windward of, refinery buildings so that alcohol vapors cannot reach the boiler room.

Ample track siding and ground storage space for fuel and raw materials are essential. Double sidings are preferable to a single track. Boiler and plant water supplies and adequate sewer facilities are of the utmost importance.

Government regulations must be complied with to the last detail, but most of these concern the storage and handling of the finished alcohol. All pipe lines must be carried in the open for complete inspection, and they must be painted in designated colors. All valves, unions, or other openings must be locked or sealed. Before any proposed operation is reduced to a tentative plan the United States Bureau of Internal Revenue should be consulted.

The cost of a plant is dependent on both size and design. The kinds of raw material to be used, the amount and type of feed recovery, the recovery of carbon dioxide gas, etc., have a great influence on the design and total cost. Geographic location is also a factor in cost. No general cost estimates can be made, but certain rough yardstick computations are possible, as indicated later.

Costs of the fermenting, refining, and miscellaneous equipment used in conventional alcohol processes can be established only indirectly. Each manufacturer of such equipment has his own ideas regarding size, design, weights of metal, types and efficiency of distilling columns and plates, etc. Therefore, refineries are frequently built throughout by one manufacturer, although specific items made or controlled by other manufacturers may be included. The general designs are about the same. Since plants are usually designed to fit local conditions or raw material, many of the large suppliers of such equipment maintain complete engineering staffs and sell the complete plants (including

foundations, equipment, erection, and complete piping) on a guarantee which includes a specific operating cost. The cost of maintaining such service is, of course, included in the gross cost of the equipment. Smaller concerns are more likely to make units to order, rather than to erect complete plants. The responsibility for successful operation of such equipment then rests largely with the purchaser, who formulates the general specifications. Costs, therefore, vary not only with the required labor and the weights of copper or other metal used, but with the degree of advisory engineering detail furnished.

The quotations presented below indicate general costs only. In no case were the bids made on an exactly comparative plan. Thus one manufacturer quotes $516,300 for a conventional-type grain-using plant having an output capacity of 10,000 gallons a day. This includes anhydrous equipment and facilities for complete slop recovery but not carbon dioxide recovery. (This estimate includes partial production of impure butanol as one stage of a proposed motor-fuel alcohol process.) These costs are further broken down in table 18 to give an idea of the distribution of cost over the entire plant.

TABLE 18.—*Distribution of plant cost*

Item	Cost	Percent of total cost
Buildings and foundations	$100,000	19.4
Boiler plant:		
Two 1,500-horsepower boilers, exclusive of foundations	18,000	
Stack and breeching, exclusive of foundations	3,500	
Oil burner, including 12,000-gallon oil storage tanks	10,000	
Miscellaneous items (boilerhouse piping, valves, etc.)	3,500	
Subtotal	35,000	6.8
Fermentation equipment:		
Conveyors:		
Mills and conveying equipment	20,000	
Track scale and hoppers, exclusive of foundations	6,000	
Truck scales, exclusive of foundations	1,500	
Grain storage, exclusive of foundations	8,500	
Cookers:		
Three cookers, including motor drives, starters, etc	13,500	
Drop tubs, including motors, drives, and starters	3,000	
Cooling system for grain-conversion unit	2,500	
Piping for grain-conversion unit	3,000	
Yeasting assembly:		
Pure-yeast-culture apparatus	3,000	
Yeast-culture propagator, double-jacketed, motors, etc	1,500	
Prefermenters, etc., drives and starters	5,500	
Piping, valves for above	1,000	
Fermenters:		
Nine 50,000-gallon ellipsoidal, closed, toncan steel ethyl alcohol fermenters, coils, etc	30,000	
Three 50,000-gallon ellipsoidal, closed, toncan steel butyl alcohol fermenters, coils, etc	12,000	
Beer well and drive	4,500	
Piping, valves, air spargers, etc., for fermenters	3,000	
Subtotal	118,500	23.0
Distillation equipment:		
Air compressor	3,500	
5-foot continuous stripping still	16,500	
5-foot 6-inch continuous alcohol rectifying unit	28,700	
7-foot continuous anhydrous unit	48,500	
4-foot continuous recovery unit	19,600	
High-speed heater	7,500	
Piping, valves, regulators, and controls for distillation units	12,500	
Subtotal	136,800	26.5

TABLE 18.—*Distribution of plant cost*—Continued

Item	Cost	Percent of total cost
Storage tanks:		
Two 12,000-gallon cistern receivers	$1,400	
Two 12,000-gallon denaturing receivers	1,400	
Two weigh-tank scales	2,500	
Benzol storage (10,000 gallons)	700	
Finished alcohol storage (2 to 50,000 gallons)	5,000	
Gasoline storage (25,000 gallons)	1,500	
Piping, and valves for above	3,500	
Subtotal	16,000	3.1
Dry-house equipment:		
Dry-house equipment, complete, utilizing flue gases	30,000	
Evaporators, complete	50,000	
Thick-slop storage tank, 25,000 gallons	1,500	
Thin-slop storage tank, 25,000 gallons	1,500	
Pumps, compressors, etc	4,500	
Subtotal	87,500	16.9
Water and power equipment:		
Wells and water storage, elevated water-storage tank for sprinkling system and supplying water	17,500	
Power and lighting, wiring	5,000	
Subtotal	22,500	4.3
Total	516,300	

Another manufacturer quotes $521,750 for a grain plant of similar size. A third manufacturer estimates the cost of a plant of the same size, exclusive of grounds, at $575,000. These include complete recovery systems, conventional process, and anhydrous equipment but are not necessarily identical as to essentials of equipment.

Still another manufacturer estimates the costs of grain-alcohol plants of conventional design, in progressively increasing sizes, as follows:

Size of plant:	*Cost of complete plant* [1]
1,000 bushel (2,500 gallons per day)	$200,000
2,000 do (5,000 gallons per day)	325,000
3,000 do (7,500 gallons per day)	450,000
4,000 do (10,000 gallons per day)	575,000
5,000 do (12,500 gallons per day)	675,000

[1] This is an over-all cost, above the ground. Cost of the buildings in this estimate is about one-third of the total sum.

Plant capacities can be doubled for about 1.4 times the initial cost, or halved at about 0.7 of the initial cost.

The cost of the distillation unit used for producing anhydrous alcohol for a 5,000-gallon per day distillery would approximate $25,000, depending somewhat on the type of process used.

Based on the above figures, table 19 is designed to show the progressive increase in capital cost as facilities for using grain for making anhydrous alcohol and for recovery of slop and carbon dioxide are added to a simple molasses plant.

TABLE 19.—*Increase and distribution of cost of alcohol plants using conventional process with partial and complete recovery of byproducts*

[10,000-gallons capacity per day]

Item	Item cost[1]	Percent of total cost				
		95 percent alcohol from molasses	Anhydrous alcohol from molasses	Anhydrous alcohol from grain (solids recovery only)	Anhydrous alcohol from grain (thin-slop and solids recovery)	Anhydrous alcohol from grain (total recovery, including CO_2)
Land (10 acres at $1,000 an acre)	$10,000	3.2	3.0	2.3	2.0	1.8
Buildings (fermenters outdoors)	80,000	25.4	24.2	18.6	16.0	14.6
Trackage and sidings	15,000	4.8	4.6	3.5	3.0	2.7
Boilers (500-horsepower, complete)	15,000	4.8	4.6	3.5	3.0	2.7
Yeasting and fermenting (Magné system—closed-top fermenters)	57,000	18.1	17.3	13.3	11.4	10.4
Distillation (including aldehyde column)	60,000	19.0	18.2	14.0	12.0	10.9
Process accessories	12,000	3.8	3.6	2.8	2.4	2.2
Storage	26,000	8.2	7.9	6.0	5.2	4.7
Piping and instruments	40,000	12.7	12.1	9.3	8.0	7.3
Subtotal for base plant	315,000	100.0				
Anhydrous unit	15,000		4.5	3.5	3.0	2.7
Subtotal	330,000		100.0			
Grain handling and grinding	65,000			15.1	13.0	11.8
Additional buildings	10,000			2.3	2.0	1.8
Driers	25,000			5.8	5.0	4.6
Subtotal	430,000			100.0		
Additional 500-horsepower boilers	15,000				3.0	2.7
Additional building space	5,000				1.0	.9
Slop evaporators	30,000				6.0	5.5
Flash driers	20,000				4.0	3.6
Subtotal	500,000				100.0	
CO_2 (solid carbon dioxide) recovery, complete	[2] 50,000					9.1
Total	550,000					100.0
Percent increase in total cost			5	36.5	58.7	74.6

[1] Approximate estimates.
[2] 22½ percent of total CO_2 recovered (7.0 tons).

BOILER PLANTS AND STEAM

In usual practice, steam requirements for distillation are based on the pounds of steam required to produce 1 gallon of alcohol, at either 95-percent or 99.5-percent concentration. Steam required to produce 95-percent alcohol is estimated at 32 to 45 pounds per gallon, depending on the use of continuous or discontinuous systems, radiation, etc. To concentrate it to the anhydrous stage requires from 8 to 15 pounds additional, depending on the process used. Recovery of byproducts requires additional steam, which may be based either on the pounds of steam required to evaporate and dry 1 gallon of slop or to produce 1 pound (or other unit) of material, or to produce 1 gallon of alcohol. Assuming that approximately 40 pounds of steam is required to produce 1 gallon of 99.5-percent alcohol and considering 34 pounds of steam per hour as 1 boiler-horsepower (34.5 actual), then 1 boiler-horsepower will produce $\frac{34 \times 24}{40}$ gallons of alcohol, or 20 gallons per day.

The investment cost of a boiler installation for the larger plants ranges from $30 to $50 per boiler-horsepower, depending on the com-

plexity of the plant. Water-tube boilers are required for steam pressures above boiler-gage pressures of 150 pounds. Boiler capacities and probable costs (exclusive of buildings or foundations) can be estimated for a given operation as follows:

$$\frac{\text{Contemplated alcohol output per day}}{20}\times\$40 \text{ (or } \$50)=X.$$ Allowing for excess needs, a 10,000-gallon plant would require, for alcohol production only, about 500 boiler-horsepower. This would cost from $15,000 to $25,000. No byproduct recovery is included in this estimate.

The steam required for feed recovery is more difficult to estimate. Corn mash may average 40 gallons of slop per bushel of corn. It may be assumed that from 70 to 92 pounds of steam is required for evaporating the slop from 1 bushel of corn, depending on the conditions of mashing, amount of re-use of spent slop, beer-still operation, filtering, etc. Rye slop cannot be evaporated so completely as corn slop.

In the case of corn, 40 gallons of slop would consist of 333 pounds of water, 7 of suspended solids, and 10 of dissolved solids. Removing the 7 pounds of solids by screening would leave 343 pounds of thin liquor. Assuming that 30 percent (a probable maximum) of this slop is re-used in the fermenters, 240 pounds containing about 7 pounds of dissolved solids, or approximately a 3-percent solution, would be left. To raise this to an arbitrary 25-percent concentration requires the elimination of 212 pounds of water. Assuming that in a triple-effect evaporator 2.3 pounds of water is evaporated per pound of steam at 15 pounds boiler-gage pressure, 92 pounds of steam would be required for evaporation of the slop. This assumes that the slop is at room temperature, although usually it is hot. Steam may also be conserved in other ways. In actual practice, when 2.5 gallons of alcohol is produced per bushel of corn, approximately 32 pounds of steam per gallon of alcohol is required for drying the slop. The possible total steam required is 72 pounds per gallon of alcohol when slop is re-used, or 85 pounds total when backslopping is not used. The latter is equivalent to 2.5 boiler-horsepower (hours) per gallon of alcohol.

To complete the concentration from a 25-percent sirup to a commercially dried end product, further heat is required. The usual practice is to mix the sirup with the separated undried solids and finish the drying operation in a rolling tubular drier, which may be steam-heated or may utilize waste stack heat. Sometimes the 25-percent sirup from the evaporators is passed through a flash drier before reaching the tubular dryer. Steam requirements for these systems vary.

In conventional-type distilleries making complete recovery of slop, the boiler capacity provided should probably be 3 to 3.5 boiler-horsepower (hours) per gallon of alcohol produced. With proper steam economy, therefore, 1 boiler-horsepower (day) capacity should be sufficient to produce from 8 to 11 gallons of alcohol per day $\left(\frac{34\times24}{72 \text{ to } 100}\right)$ in a plant making complete slop recovery.

DRY-HOUSE EQUIPMENT

The estimated cost of triple-effect evaporators for handling the slop from alcohol plants of various sizes is shown below.

Plant capacity per day:	
2,500 gallons	$15, 000
5,000 gallons	22, 000
10,000 gallons	35, 000

One manufacturer submitted the following information with reference to evaporators. The price estimates shown are now probably out of date, but the progressive cost requirements are clearly demonstrated.

Evaporators should be at least double-effect for small plants, triple for medium plants, and quadruple for large plants. Table 20 shows the purchase cost of evaporators of various capacities and the daily cost of operation, including all factors, that gives a concentration up to 28 percent. The operating costs are based on the following: Steam at 30 cents per thousand pounds, water at 2 cents per thousand gallons, power at three-fourths of a cent per kilowatt-hour, labor at 50 cents an hour, maintenance at 5 percent of installed cost, interest and depreciation at 15 percent of installed cost, backward feed, 150° F. feed, 210° exit, and 205 pounds of total slop feed per bushel of corn. In triple-effect evaporators the best feed is from the second effect to the third and then through the first effect, using a calandria as the last or No. 1 effect, and long-tube evaporators for the second and third effects, with a 26-inch vacuum.

TABLE 20.—*Purchase and operating costs of evaporators of various capacities*

Plant capacity (bushels of raw material per day)	Triple effect				Daily operating cost of—			
	First cost [1]	Steam consumption	Cooling water at 75° F.	Shipping weight	Double effect	Triple effect	Quadruple effect	Quintuple effect
		Pounds	*Gallons per minute*	*Pounds*				
1,000	$8, 500	3, 400	160	42, 500	$58. 00	$47. 00	$40. 00	$51. 00
2,000	14, 400	6, 800	320	85, 000	110. 00	82. 00	70. 00	76. 00
4,000	25, 000	13, 600	64	114, 000	215. 00	150. 00	128. 00	124. 00

[1] Add 12 percent for piping, plus 10 percent for present price of triple, 33⅓ percent for quadruple, and 66⅔ percent for quintuple.

Flash driers may cost from $20,000 to $23,000 for the 5,000- and 10,000-gallon plants. The cost of a complete dry house, including evaporators, roller driers, flash driers, blowers, cyclones, and bagging equipment, using steam for drying, was estimated by one manufacturer as follows:

Plant capacity:	
2,500 gallons	$70, 000
5,000 gallons	90, 000
10,000 gallons	125, 000
15,000 gallons (plus $50,000 additional for boiler expansion)	145, 000
15,000 gallons (solids recovery only; no evaporation of thin slop)	55, 000

In one of the estimates previously shown for the complete alcohol plant, a dry house in which flue gas is used for drying is quoted at $87,500.

In producing motor-fuel alcohol the cost of the dry-house part of the process is not expected to be less than that of the conventional process since the requirements are largely the same. However, there may be differences in the normal quantity of byproduct received at the dry house.

Storage

Motor-fuel alcohol would probably be produced from various kinds of low-grade raw materials if culls or surpluses were used. Storage and conveyor systems, therefore, should be designed to handle various types of material. Since the materials may be infected upon arrival, it is believed that sterilization, before fermenting, will be required. In designing the plant, therefore, provision should be made for steam sterilization. Storage bins, weighing scales, conveyor lines, etc., should also be sterilized to prevent the spread of infection to successive batches of raw materials. Infection causes loss in yield and the production of other chemical compounds besides alcohol.

Starch Conversion

The carbohydrates of the raw materials that would probably be used for the production of motor-fuel alcohol include fiber and pentosans, which are not fermentable by yeast, as well as starches, inulin, sucrose, reducing sugars, etc. Since yeast in general can ferment only the common hexose sugars, all the possible convertible carbohydrate content must be hydrolyzed to reducing sugars in order to secure the utmost yield of alcohol. In the United States starch is converted commercially with malt. In the production of motor-fuel alcohol, conversion with malt has the following objections: (1) The high cost of the malt; (2) the time and careful control required to hold the cooked mash at a certain temperature to insure complete diastatic action; (3) the inability of malt to convert fiber, pentosans, and some sugars to a fermentable form.

The possibility of using green malt, particularly in isolated plants, should be considered. Green malt, which might be manufactured in the plant, is superior to dry malt in diastatic value, since the enzyme suffers in the usual drying process (*27, p. 339*). Experimentation on the use of natural inverting substances present in some raw materials may be worth while.

It has been claimed that a higher degree of total conversion of carbohydrates is effected by the so-called amylo (or mold) process than by the malt process (*55*). Consideration might be given to the use of the amylo procedure, provided that the longer time required for this process does not nullify any possible gains. Possible criticism of the amylo process in regard to presumed influence on the taste or odor of the product have no significant bearing in producing motor-fuel alcohol.

In lieu of malt, a more complete saccharification of the carbohydrates may be possible with dilute mineral acid. Temperature control would not be so important in this case, and, as compared with the cost of malt, the cost of the acid is negligible. On the other hand, acid-resisting equipment would have to be used. Copper, copper alloy, or other special alloy metal equipment might resist the action of a 2-percent sulphuric acid concentration, under pressure-cook conditions, and the excess acid might be subsequently neutralized

with ammonia to form ammonium sulphate, which is frequently added to molasses fermentations to speed up the action of the yeast. The acid might also be neutralized with lime, and the calcium salt recovered as an ingredient of the byproduct stock feed. Considerable research will be required on the whole acid-conversion premise. Care must be taken that copper salts are not formed in amounts sufficient to inhibit yeast action. (Yeast is ordinarily propagated in copper equipment, which, however, is usually tin-lined.)

This cooking with acid under pressure should sterilize the mash sufficiently to allow the use of specific pure cultures of yeast.

Yeasting

The use of an automatic yeast-propagating system (fig. 25), such as the Magné (*48*), may eliminate costly yeast-room and bacteriological-laboratory operation and equipment. In this process, one charge of pure-culture yeast in the upper drum of the apparatus is intended to produce subsequent pure-culture yeast mashes for a long period. The cost of the original equipment is probably less than the cost of the usual yeast-mash-propagation assembly. It may be operated by semiskilled labor. Under favorable conditions, the maintenance of a bacteriological culture laboratory might be avoided by the use of commercial compressed yeast. Pure lactic acid cultures might be employed to control fermentation conditions.

In the fermentation process a certain amount of the sugar in the wort is consumed in building yeast, and a correspondingly lower alcohol yield is secured. The yeast cells still retain vitality at the end of the fermentation. A recent development consists in centrifuging these yeast cells from the beer, before distillation, and re-using the recovered yeast in subsequent fermentations, thus conserving the sugar otherwise required for producing an equivalent quantity of organisms. Higher alcohol yields may result, provided there is no detrimental contamination of such yeast stock.

Process Economies

Mashes should be processed and fermented at the maximum concentration possible, to cut down heat requirements for subsequent evaporation.

Re-use of water and steam is essential. Cool water, of course, is required at the condensers. The warmed exit water may be re-used, however, for diluting mashes, boiler feed, and washing. Backsetting, or re-use of portions of the spent slop, might be found advisable. For large plants, steam is more economical if produced at high pressure and passed through a turbine or other power abstractor, from which electric power may be secured for use in grain handling equipment, pumps, etc. By this method high-pressure steam is available for certain uses, and the low-pressure steam may subsequently be used for distillation and evaporation. If cheap electric power is available, however, the use of low-pressure boilers would probably be more logical. The availability and cost of respective fuels influence the design of the steam-generating system.

Practically all the industrial alcohol plants in the United States are built to use only one type of raw material, that is, either grain or

molasses. Since motor-fuel alcohol plants might have to use a variety of materials, frequently of poor quality, this fact should be considered in the design of the plant. The principal change or enlargement from the conventional process would occur in the raw-material storage, handling, and preparation part of the plant. The design of the beer

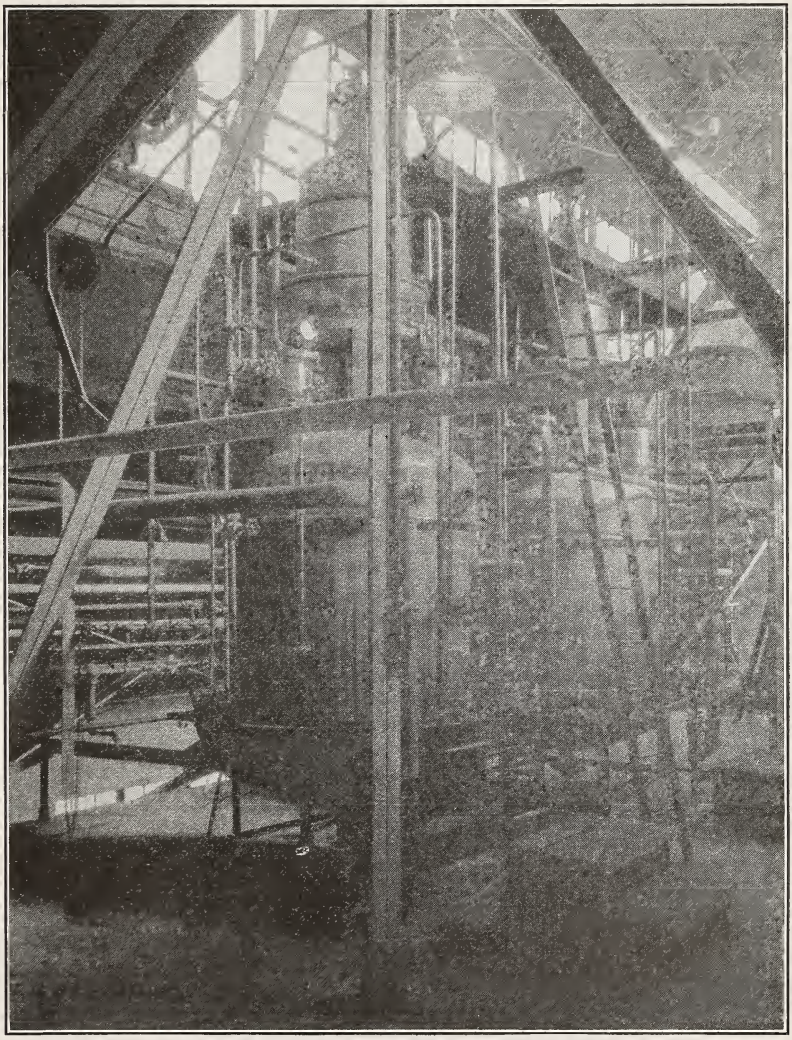


FIGURE 25.—Yeast culture machines (Magné type).

column need not be affected, provided there is suitable prescreening. In the byproduct-feed recovery, minor alterations might be required. If raw materials low in sugar content are to be used, the fermentation capacity must be increased or a concentration effected by evaporation. The latter step introduces additional cost. The conventional one-

material plant can be changed to an all-purpose plant for perhaps a 15-percent increase in the total capital investment.

In the conventional alcohol process the dilute fermented mash is fed to a beer column, which is usually equipped with a section of refining (or concentrating) plates at the top. The alcohol is removed by injecting live steam through spargers in the base of the column (fig. 26). The warm incoming mash is heated by the hot escaping alcohol vapors and waste slop by means of suitable heat exchangers. The heat balances are such that this operation is accomplished with reasonable economy if no byproducts are to be recovered from the slop. The dealcoholized liquor from the beer still is diluted by the live steam condensed in the alcohol-removal process, throwing an extra load on the evaporators and raising the total cost of the oper-

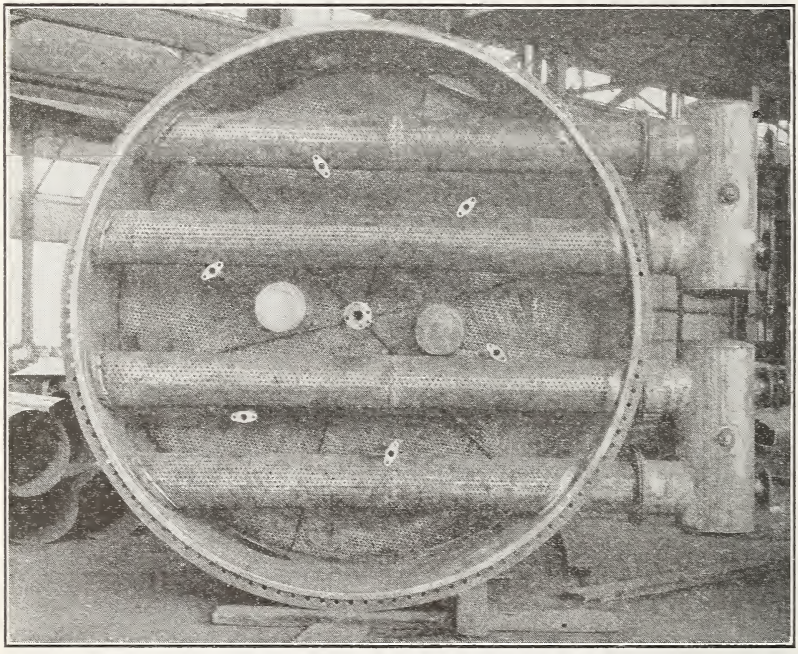


FIGURE 26.—Steam spargers and stripping plates used in beer columns.

ation if the slop is to be subsequently evaporated. Savings in steam are possible by the methods of Chute (*21*), Reich (*58*), the Vulcan Copper and Supply Co. as described by Othmer (*54*), and others. In these methods fermented beer is passed into the evaporators or other heat exchangers, for example as a byproduct from the slop evaporation, the vapors being used to accomplish secondary boiling effects similar to the action in a multiple-effect evaporator. By such means the beer-still operation can be wholly or partly eliminated or its cost reduced.

The equipment used for the conventional alcohol process is largely copper, particularly the refining apparatus (fig. 27). This is usually so designed that the elimination of water from the crude weak alcohol

also removes impurities. It may be possible to reduce capital and labor and fuel costs by substituting cheaper metals for copper; by designing the columns to permit more rapid passage of the alcohol vapor, thereby producing 95-percent material without removing certain impurities; by the use of vacuum or pressure distillation and

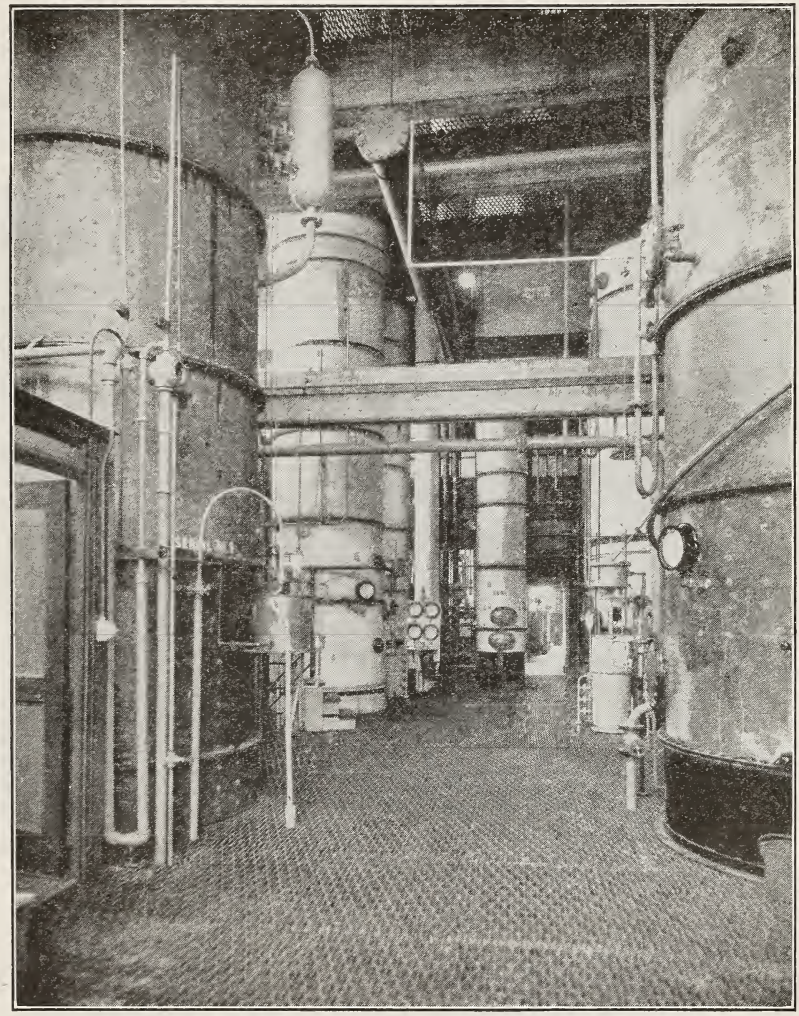


FIGURE 27.—Typical distillation columns.

more efficient heat exchangers; by the combination of certain process steps or double use of certain items of equipment, and by centralizing control (fig. 28). Theoretical ways of effecting economy, as discussed here, are concepts that should be proved experimentally before final adoption.

BYPRODUCTS

Stock Feed

The recovery of stock feed from the distillery wastes is an essential part of motor-fuel alcohol operation. The type of equipment used is shown in figures 29, 30, and 31. A distinction may be made as to the completeness of recovery. With certain raw materials, it may be more economical to screen out the solids from the spent slop and dry them for sale, allowing the filtrate to run to the sewer. With other materials there may be sufficient dissolved solids to warrant the evaporation of the thin slop. Before equipping the feed-recovery plant, therefore, the raw material to be used should be considered.

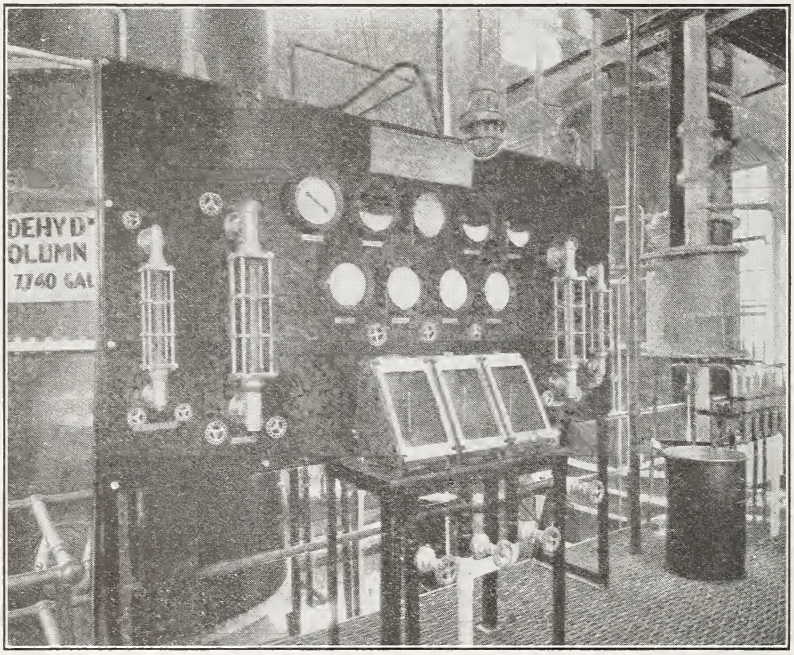


Figure 28.—Control panel for large modern alcohol refinery.

Where stream pollution is forbidden, complete recovery might be necessary.

The investment cost of a dry house can be roughly divided into one-third for drying of filterable solids and two-thirds for thin-slop evaporation. Steam requirements for evaporation are greater than the requirements for the alcohol distillation, but for simple drying of filterable solids the waste heat from the boiler-flue gas might be used if it were controlled sufficiently to avoid burning the product.

Table 3 (page 27) shows the probable pounds of residual solids per ton of various raw materials. These figures represent the sum of the fiber, mineral matter, and other unfermentables. In actual practice, these amounts may be increased by the presence of dead yeast cells, unfermented sugars, etc.

There is no national or uniform fixed standard of composition for alcohol-byproduct feeds, but most States have established regulations covering the sale of such products, usually in reference to quantities of protein, fat, and fiber. The market value depends on the respective percentages of digestible fats, proteins, and other nutrients present. Naturally, the product must not be scorched in the drying process or otherwise made unpalatable.

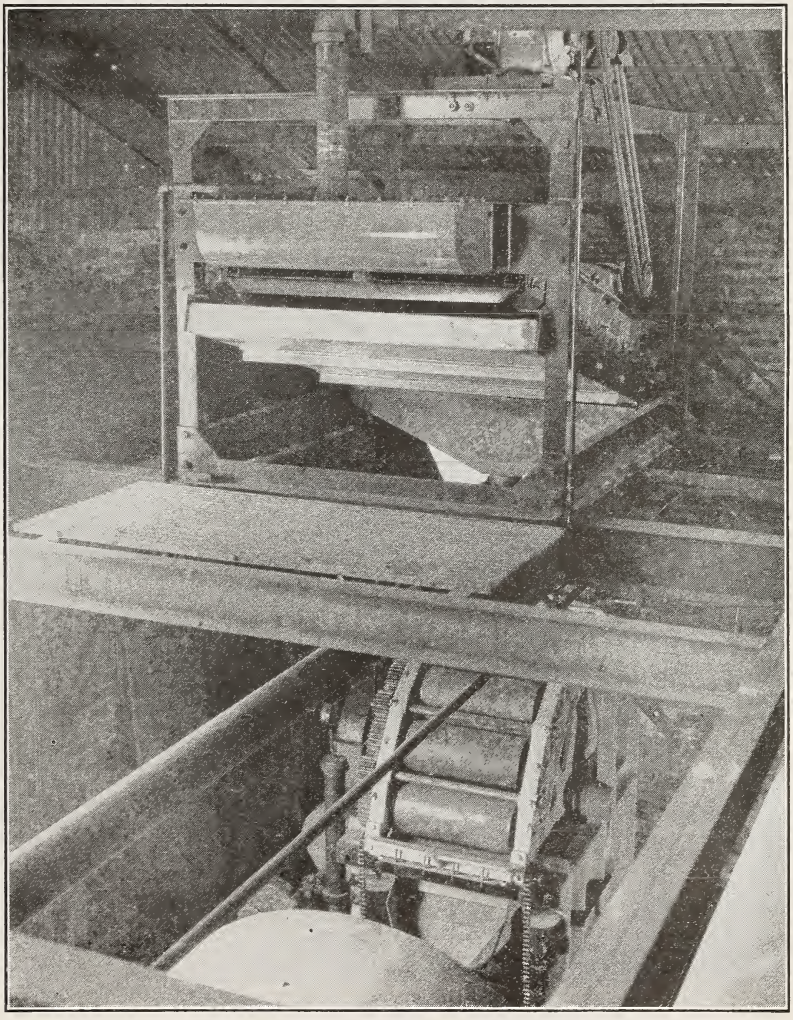


FIGURE 29.—Vibrating screen and dewatering press for recovery of byproduct grains.

Some misconception may exist as to the actual value of the feed, distillers' grains, or distillery slop, obtainable as byproducts from some raw materials. There is a tendency in some cases to credit these by-products with a high market value, sometimes even not deducting the necessary costs of processing. The price of alcohol-byproduct feed-

stuffs would probably follow the market price for grain feeds. Therefore, when the price of cereals is low, the byproduct feeds would likewise probably bring a low price, although they might command a slightly favorable differential because of the higher digestible protein content. Semple and Shepherd [14] state that "when the haul is short, distillers' wet corn grains are an economical feed if they are as cheap

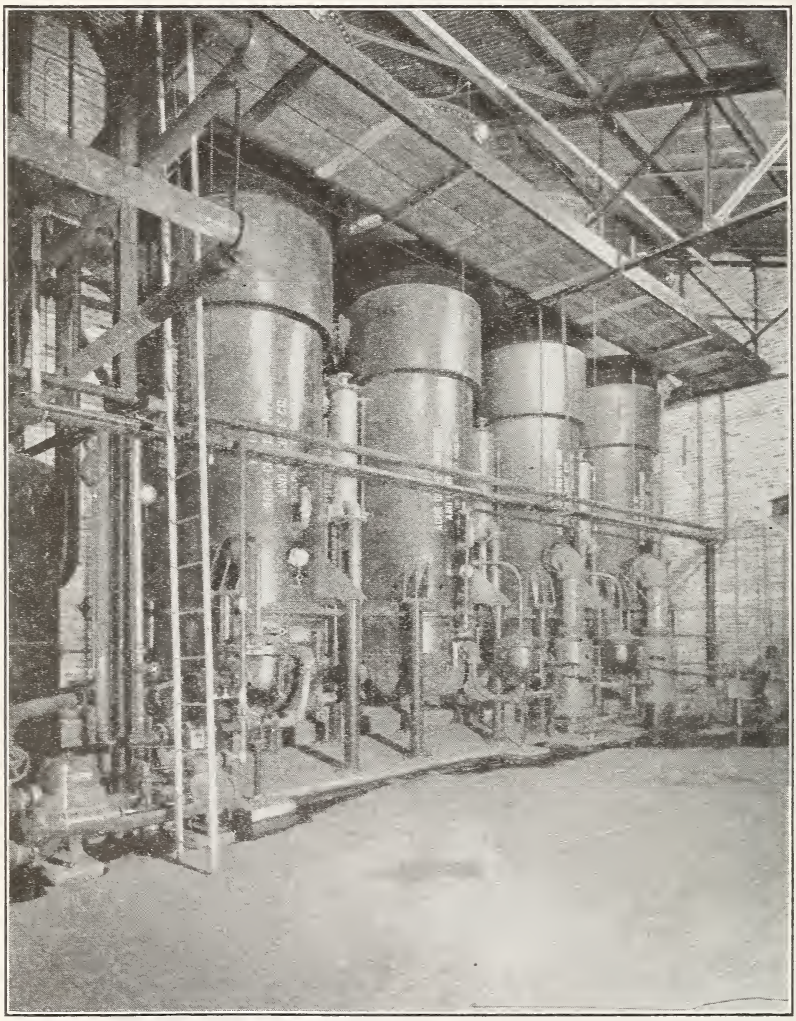


FIGURE 30.—Quadruple evaporators for recovery of thin slop.

as silage or if they can be purchased at one-fourth or less the price of grains. Distillers' wet rye grains are not an economical feed unless they are somewhat cheaper." They also say:

The proteins of distillers' dried corn grains, so called because of the principal ingredient, are derived chiefly fron corn and barley. While these proteins are

[14] SEMPLE, A. T., and SHEPHERD, J. B. BREWERY, DISTILLERY, VINEGAR, AND YEAST BYPRODUCTS FOR FEEDING LIVESTOCK. U. S. Bur. Anim. Indus., Anim. Husbandry Div. Mimeograph No. 1, 9 pp. 1935.

deficient in some of the essential amino acids, they are useful for supplementing the proteins in other concentrates and roughages. The proteins of distillers' dried rye grains are of lower quality than those of the corn grains. Since this feed is also low in digestible nutrients, it is not an economical feed unless the price is considerably below that of wheat bran and farm grains.

The nutritive ratio may be defined as the ratio between the amounts of digestible protein and other digestible nutrients (usually fats and carbohydrates) in the feedstuff.

It is generally admitted among feeders that a higher percentage of protein is required for young and growing animals, smaller percentages

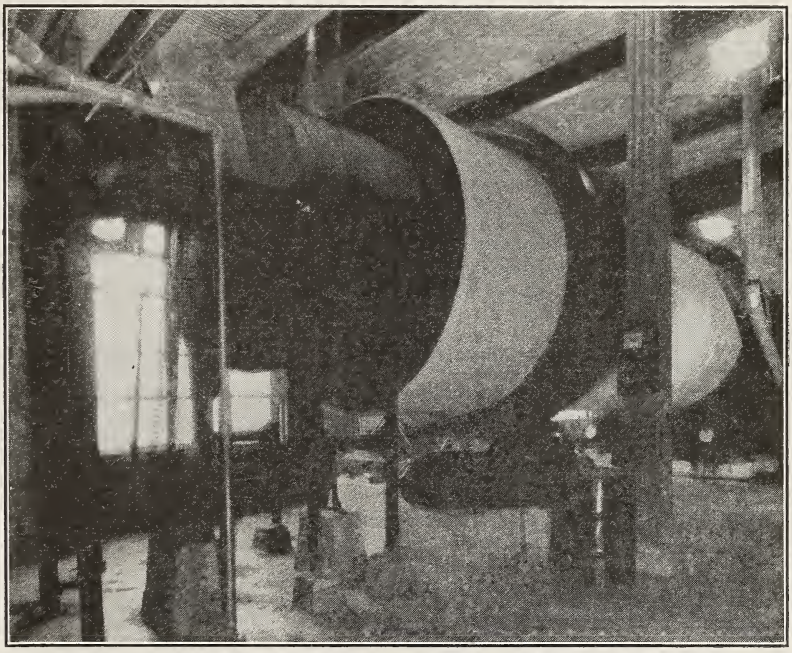


FIGURE 31.—Rotary drier for distillers' grains.

being satisfactory for more mature animals which are being fattened.

Table 21 presents a comparison of the usual composition of various natural feedstuffs and of feeds normally recovered as alcohol byproducts, according to analyses selected from various sources. From this table it is evident that distillers' grains, distillers' slops, and alcohol-byproduct feedstuffs constitute a special type of feed, comparatively low in sugar and starch (carbohydrates as nitrogen-free extract) but high in protein, fat, and fiber. The use of these products as stock feed, therefore, is restricted.

TABLE 21.—*Composition of usual feedstuffs as compared with that of feeds normally recovered as byproducts of alcohol production*

Feedstuff	Total dry matter	Digestible protein	Total digestible nutrients	Nutritive ratio [1] 1:	Average composition					
					Protein	Fat	Fiber	Nitrogen-free extract	Mineral matter	Moisture (water)
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Barley, common (*49*)	90.4	9.3	78.7	7.5	11.8	2.0	5.7	68.0	2.9	9.6
Beet pulp dried molasses (*49*)	91.8	6.1	74.3	11.2	9.9	0.7	15.9	60.1	5.2	3.2
Brewer's grains (*49*)	92.6	21.5	65.7	2.1	26.6	6.8	14.6	41.0	3.6	7.4
Corn, Dent, Grade No. 1 (*49*)	87.2	7.3	82.5	10.3	9.6	3.9	2.3	70.0	1.4	12.8
Corn, Dent, Grade No. 3 (*49*)	83.5	7.0	79.0	10.3	9.2	3.8	2.2	67.0	1.3	16.5
Corn, Dent, Grade No. 5 (*49*)	78.5	6.6	74.2	10.3	8.6	3.6	2.0	63.0	1.3	21.5
Cottonseed meal (*49*)	93.0	37.8	80.9	1.1	45.5	7.8	9.0	25.2	5.5	7.0
Grain sorghum (*49*)	88.6	9.1	80.1	7.8	11.2	3.0	2.3	70.3	1.7	11.4
Oats (all varieties) (*49*)	91.1	9.4	71.5	6.6	12.0	4.7	10.6	60.2	3.6	8.9
Wheat (all varieties) (*49*)	89.8	11.3	83.6	6.4	13.1	1.7	3.0	70.0	2.0	10.2
Molasses, beet (*49*)	80.6	2.5	58.8	22.5	7.7	-------	-------	62.6	10.3	19.4
Molasses, sugarcane (*49*)	74.1	0.9	56.6	61.9	2.8	-------	-------	61.9	9.4	25.9
Potato flakes, dried (*49*)	87.9	3.6	77.2	20.4	7.1	.3	2.9	73.6	4.0	12.1
Soybeans (*49*)	90.2	32.8	86.2	1.6	36.9	17.2	4.5	26.3	5.3	9.8
Alcohol-byproduct feed (*49*)	92.6	20.1	59.9	2.0	31.4	9.2	9.2	30.9	11.9	7.4
Distillers' corn grains, dried (*49*) [2]	93.6	22.3	85.0	2.8	30.6	10.6	10.8	38.7	2.9	6.4
Distillers' rye grains, dried (*49*) [2]	94.0	10.1	62.9	5.2	18.1	6.9	17.0	48.8	3.2	6.0
Distillers' potato slop, air-dried (*27, 84*)	88.0	12.5	35.0	1.8	24.9	2.9	9.9	39.2	11.1	12.0
Distillers' rye slop, dried (*49*)	88.0	16.8	51.3	2.1	30.0	3.0	8.0	38.0	9.0	12.0
Distillery slop, whole (*49*)	6.2	1.2	4.9	3.1	1.9	.6	.5	2.9	.3	93.8

[1] The ratio of digestible protein to the total digestible nutrients other than digestible protein is called the nutritive ratio.

[2] Distillers' dried grains are produced by draining off the excess water from distillery slop and then drying it.

Crude fiber is digested to a considerable degree by Herbivora, such as cattle, sheep, and horses. This may be the result of microbial action in the digestive tract rather than direct metabolism. Pigs are able to utilize crude fiber only to a very limited extent. The feed value of the proteins depends on the presence of certain essential amino acids, and, therefore, a high protein content of the feed may not indicate high feed value (*49*). Thin slop (unevaporated, filtered fermenter waste) or settled slop (the filtered out, undried solids therefrom) is sometimes fed directly to animals, but these should be supplemented with good carbonaceous feed and supplementary protein to at least 20 percent by weight of the thin slop, otherwise the carcasses, especially of pigs, may not meet trade standards, and the meat may be soft or oily (*85*).

CARBON DIOXIDE

Recovery of carbon dioxide gas would necessitate the use of closed-top fermenting tanks, which are more expensive and perhaps more difficult to clean and sterilize than open-top tanks. Additional compressors, presses, and conveyors would also be required, as well as some additional steam and labor. The market demands a gas product entirely free from taste and odor. The manufacturing process is technically simple. The gas from the fermenters is scrubbed with appropriate washing solutions (*57*) or drawn through activated carbon (*10, 11*) and then compressed into cylinders for sale as a liquid. The liquid gas may be changed to solid form (snow) by further freezing or

expansion and then compressed in hydraulic presses for sale in insulated containers as solid carbon dioxide.

Costs for a complete plant may be estimated as ranging from $5,000 to approximately $7,000 per ton of product per day. Production costs might range from $2 to $10 per ton. As the process is largely mechanical, comparatively little labor would be required. The greatest expense would probably lie in the marketing and distribution of the product. No definite figures as to distribution costs can be quoted here. The sales return ranges from $20 to $40 per ton, but it may run as high as $80 per ton when the product is dispensed in small containers, with corresponding increase in distribution costs. There seems to be an expanding market, which, however, is somewhat seasonal. Carbon dioxide in solidified form suffers from a first-day evaporation loss of 4 to 8 percent; under favorable conditions, subsequent evaporation may be as low as 2 percent per day.

While in some cases the weight of the carbon dioxide produced by fermentation is approximately one-half the weight of the raw material used, the distribution of actual energy represented is quite different. From an energy standpoint the carbon dioxide produced from 1 g-mol of glucose represents only 25.8 kg-calorie units, the remaining 651.4 units being in the alcohol produced. This means that less than 4 percent of the total combustible energy of the sugar has been lost in the gas.

As for other possible uses for the waste gas, it might serve as a base for the production of synthetic organic compounds, provided the cost of the additional energy required could be offset by the financial return from the resulting product. The gas when in solution as carbonic acid might be used under pressure for the hydrolysis of starch or sucrose.

The net profit possible from the carbon dioxide gas may be estimated at about 2 cents per gallon of alcohol produced. About 44 pounds of carbon dioxide are produced for each 46 pounds of alcohol. For example, in a molasses fermentation, if the production cost for recovery of solid carbon dioxide is assumed to be $10 a ton and the price return $25 a ton (f. o. b. the plant) the net profit would be $15 a ton (exclusive of evaporation and distribution losses and costs, which must be offset by increased sales prices). Accordingly, for each 1,000 gallons (6,600 pounds) of alcohol there would be available for recovery $6{,}600 \times \frac{0.514}{0.538} = 6{,}306$ pounds (3.15 tons) of carbon dioxide, worth $47.25. This would be equivalent to 4.72 cents per gallon of alcohol.[15] In actual practice under present market conditions, however, it is usually necessary to build a recovery plant which will operate only seasonally and probably at only about 40 percent of its rated capacity, the excess capacity being required to meet occasional peak-load conditions in hot weather and to compensate for fluctuations in the concentration and supply of raw input gas. A 40-percent return would reduce the calculated 4.72 cents return to about 1.89 cents per gallon. Actual profit would vary, therefore, with the level of recovery. If a sulphuric acid scrubbing process is used for purifying the gas, this acid may subsequently be re-used for fermentation purposes, and charged either to the alcohol or to the gas. The values quoted above

[15] It is usually impracticable to recover more than 70 percent of the total gas evolved.

are gross returns; the net return would depend on how the process costs were charged to the entire plant operation. In some instances carbon dioxide-recovery plants operating on distillery gas are not owned by the alcohol plant but merely purchase the raw gas.

Fusel Oil

During an ordinary yeast fermentation a small quantity of oil having a characteristic odor is formed. This oil is normally separated from the alcohol in the refining columns. It consists of a mixture of higher alcohols and esters, principally amyl, but the composition varies with different fermentation conditions and different raw materials. The oil seems to be produced in connection with amino acid decomposition and may not necessarily originate from the sugar (*32, p. 81*), although pentosans, or bacterial action other than yeast, may sometimes form similar compounds (*27*).

The following typical analysis (percentage) of fusel oil from potatoes is given by Delbrück (*27*): *n*-Propyl alcohol, 6.85; isobutyl alcohol, 24.35; amyl alcohol, 68.76; acids, esters, and furfural, 0.04. In ordinary molasses fermentations about 1 gallon is recovered for each 1,000 gallons of ethyl alcohol produced. Corn and potatoes yield slightly higher amounts.

Ordinarily, fusel oil is not refined but is sold as recovered, after the water-soluble ethyl alcohol fraction is removed. It is used principally as a solvent for lacquer, without separation into its components. Practically no distinction is now made by the trade as to the material from which the oil originates, although corn and molasses are the only commercial sources at present.

Byproduct Credits

Some estimates of the value of agricultural products used for alcohol motor fuel can be computed. The successful rule of the industrial-alcohol industry has been expressed in the phrase "a cent a pound for raw material." Raw materials for fuel alcohol cannot be expected to command a price greater than this, and actually such price would have to be less, unless the cost of producing the alcohol could be relatively reduced. This reduction is largely dependent on the profit from the byproducts.

Table 22 presents computations on the more likely crops. These indicate the effect of byproduct credits at several price scales for the raw material. It can be seen that at 1 cent a pound the various cereals will have net values of 12 to 17 cents per gallon of alcohol. Potatoes are relatively more expensive. In this table credit has been included for feed, miscellaneous byproducts, and part of the carbon dioxide.

TABLE 22.—*Cost of raw materials per gallon of absolute alcohol*

[After allowable credits for byproducts have been deducted]

Raw material	Unit	Cost range per raw material unit	Allowable credits for—					Gross raw material cost	Net raw material cost [2]
			Feed	Fusel oil [1]	Carbon dioxide	Miscellaneous	Total		
		Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Barley	Bushel	36	4.43	0.50	1.89		6.82	18.95	12.13
		48	6.07				8.46	25.25	16.79
		60	7.71				10.10	31.57	21.47
Corn	do	42	3.58	1.60	1.89	[3] 4.27	10.74	17.80	7.06
		56	4.91				12.07	23.73	11.66
		70	6.24				13.40	29.66	16.26
Grain sorghum	do	42	4.14	.50	1.89		6.53	18.90	12.37
		56	5.68				8.07	25.20	17.13
		70	7.21				9.60	31.50	21.90
Molasses, blackstrap	Gallon	4		.40	1.89	[4] 1.50	3.79	10.00	6.21
		6						15.00	11.21
		8						20.00	16.21
Oats	Bushel	24	8.97	.50	1.89		11.36	23.50	12.14
		32	12.30				14.69	31.37	16.68
		40	15.63				18.02	39.20	21.18
Potatoes	do	10	.60	1.25	1.89		3.74	14.50	10.76
		30	1.41				4.55	43.50	38.95
		60	3.07				6.21	87.00	80.79
Sweetpotatoes	do	14	.48	.50	1.89		2.87	14.65	11.78
		28	1.15				3.54	29.30	25.76
		55	2.49				4.88	58.50	53.62
Rye	do	42	4.64	.50	1.89		7.03	19.10	12.07
		56	6.36				8.75	25.44	16.69
		70	8.08				10.47	31.81	21.34
Wheat	do	45	4.28	.50	1.89		6.67	17.50	10.83
		60	5.86				8.25	23.30	15.05
		75	7.45				9.84	29.20	19.36

[1] Based on net profits from these byproducts computed at current sale-price quotations.
[2] After deductions for byproducts.
[3] Degermination of corn will allow 3 cents for corn oil and 1.27 cents for oil press cake, but will probably decrease the value of the feed.
[4] Potash recovery credit, allowable only on slop of molasses fermentation.

Table 23 shows the cash return that may probably be expected by the farmer for crops used for alcohol The gross-acre cash return is calculated for average, normal, and high acre yields, at the base price of 1 cent a pound for the raw materials and also at the respective prices necessary to allow a per gallon raw-material investment of 14 cents, which seems to be a good general index value. It is obvious that increased acre yields would give greater gross returns.

TABLE 23.—*Anticipated farm income from converting crops into alcohol*

Raw material	Price per bushel	Yield (76) of raw material per acre			Anticipated yield of 99.5-percent alcohol per acre (based on average fermentable content)			Estimated annual gross farm return per acre based on—		
		10-year average for United States	10-year average for chief producing area	1-year high yield for a single State	Average for United States	Average for chief producing area	1-year high yield for a single State	Average for United States	Average for chief producing area	1-year high yield for a single State
	Cents	*Bushels*	*Bushels*	*Bushels*	*Gallons*	*Gallons*	*Gallons*			
Barley	[1] 48 [2] 46	22.6	25.2	49.0	43.0	47.9	93.0	$10.85 10.40	$12.10 11.57	$23.52 22.54
Corn	[1] 56 [2] 65	25.4	37.8	55.0	59.6	88.8	129.2	14.22 16.51	21.17 24.57	30.80 35.75
Grain sorghum	[1] 56 [2] 53	14.7	16.0	34.0	32.6	35.5	75.5	8.23 7.79	8.96 8.48	19.04 18.02
Oats	[1] 32 [2] 31	30.2	35.6	57.0	30.8	36.3	58.2	9.66 9.36	11.39 11.04	18.24 17.67
Potatoes (Idaho)	[1] 60 [2] 14.7	------	------	250.0	------	------	172.5	------	------	150.00 36.75
Potatoes (Maine)	[1] 60 [2] 14.7	------	------	325.0	------	------	224.5	------	------	195.00 47.78
Potatoes (Michigan)	[1] 60 [2] 14.7	------	------	150.0	------	------	103.5	------	------	90.00 22.05
Potatoes (general)	[1] 60 [2] 14.7	112.7	258.0	325.0	77.8	178.0	224.5	67.62 16.56	154.80 37.93	195.00 47.78
Sweetpotatoes	[1] 55 [2] 19.5	96.0	150.0	400.0	90.1	141.0	376.0	52.80 18.72	82.50 29.25	220.00 78.00
Rye	[1] 56 [2] 54	10.8	12.0	20.2	23.8	26.4	48.4	6.05 5.83	6.72 6.48	11.31 10.91
Wheat	[1] 60 [2] 62	13.0	14.7	30.4	33.0	37.4	77.2	7.80 8.06	8.82 9.11	18.24 18.85

[1] Based on 1 cent a pound for raw material as a return to the farmer.
[2] Based on net cost of 22 cents per gallon for undenatured, anhydrous alcohol, f. o. b. storage tanks at refinery, 14 cents of which has been taken as representing raw-material net cost. Credits for byproducts usually recovered have been deducted.

These two tables do not, however, present all the facts. The different raw materials not only yield varying amounts of alcohol and byproducts per acre but entail different total expense for conversion into alcohol. Table 24 shows this variation in conversion costs, as well as other comparisons. The figures in table 24 are assumptions or estimates only, based on data in previous tables or other available information. They are intended to show approximately what the over-all cost of alcohol produced from the several materials would be, in comparison with molasses at 3, 5, or 7 cents per gallon, when anticipated returns from feed and fusel oil byproducts are credited against the probable operation costs. These byproducts would probably be recovered in any motor-fuel alcohol operation, except perhaps when the yield of byproducts was low. Since carbon dioxide is less likely to be recovered, credit for this is not included. The price of feed byproducts is considered to be the same as the price of the original raw material less $1.50 per ton for handling, except that for very low priced crops the value is arbitrarily taken at $10.00 per ton. The malting costs necessary for operating on starchy materials have not been included because of the complexity which would be introduced into the table.

TABLE 24.—*Comparison of farm crops and molasses as raw materials for the production of alcohol*

Raw material [1]	Material required for 100 gallons of alcohol	Price per ton	Total cost of raw material for 100 gallons of alcohol	Probable conversion cost for 100 gallons of anhydrous alcohol [2]	Byproduct credits [3] per 100 gallons of alcohol: Items	Byproduct credits [3] per 100 gallons of alcohol: Value	Net cost for 100 gallons of anhydrous alcohol	Unit cost of raw material f. o. b. distillery [4]
	Tons							
Molasses, sugarcane, blackstrap (170 gallons per ton).	1.42	$5.10	$7.24	$8.00	Fusel oil	$0.40+1.50	$13.34	$0.03
		8.50	12.24		Potash		18.34	.05
		11.90	17.14				23.24	.07
Corn (56 pounds per bushel; 35.7 bushels per ton).	1.19	9.27	11.03	[5] 10.80	Fusel oil	1.00+2.49	18.34	.26
		20.00	23.80		Feed	1.00+4.91	28.69	.56
		26.78	31.87			1.00+6.76	34.91	.75
Grain sorghum (56 pounds per bushel; 35.7 bushels per ton).	1.26	8.30	10.46	[5] 11.10	Fusel oil	.50+2.72	18.34	.23
		20.00	25.20		Feed	.50+5.68	30.12	.56
		25.00	31.50			.50+7.21	34.89	.70
Rice, rough (45 pounds per bushel; 44.4 bushels per ton).	1.26	8.25	10.40	[5] 11.15	Fusel oil	.50+2.71	18.34	.19
		20.00	25.20		Feed	.50+6.06	29.79	.45
		26.64	33.57			.50+8.23	35.99	.60
Rye (56 pounds per bushel; 35.7 bushels per ton).	1.27	8.09	10.27	[5] 11.35	Fusel oil	.50+2.78	18.34	.23
		20.00	25.40		Feed	.50+6.36	29.89	.56
		25.00	31.75			.50+8.08	34.52	.70
Wheat (60 pounds per bushel; 33.3 bushels per ton).	1.18	9.55	11.27	[5] 10.60	Fusel oil	.50+3.03	18.34	.23
		20.00	23.60		Feed	.50+5.86	27.84	.60
		26.78	31.60			.50+8.03	33.67	.75
Jerusalem-artichokes (60 pounds per bushel; 33.3 bushels per ton).	5.00	1.91	9.54	[5] 10.80	Fusel oil	.50+1.50	18.34	.06
		20.00	100.00		Feed	.50+4.81	104.49	.60
		10.00	50.00			.50+3.00	57.30	.30
Potatoes (60 pounds per bushel; 33.3 bushels per ton).	4.37	2.25	9.85	[5] 11.15	Fusel oil	1.25+1.41	18.34	.07
		20.00	87.40		Feed	1.25+3.07	94.23	.60
		10.00	43.70			1.25+1.41	52.19	.30
Sweetpotatoes (55 pounds per bushel; 34.2 bushels per ton).	2.92	3.22	9.39	[5] 10.60	Fusel oil	.50+1.15	18.34	.09
		20.00	58.40		Feed	.50+2.49	67.01	.55
		8.55	25.03			.50+1.15	31.93	.25
Sugar beets (60 pounds per bushel; 33.3 bushels per ton).	4.52	2.51	11.34	9.00	Fusel oil	.50+1.50	18.34	.08
		20.00	90.40		Feed	.50+4.18	94.72	.60
		8.33	37.67			.50+2.75	43.42	.25
Sugarcane (Louisiana)	6.58	1.47	9.64	9.20	Fusel oil	.50− .00	18.34	1.47
		20.00	131.60			.50− .00	140.30	20.00
		3.50	23.03			.50− .00	31.73	3.50
Apples, all varieties (48 pounds per bushel; 41.7 bushels per ton).	7.00	1.53	10.74	9.50	Fusel oil	.50+1.40	18.34	.04
		20.00	140.00		Feed	.50+2.59	146.41	.48
		5.00	35.00			.50+1.40	42.60	.12
Grapes (all varieties)	6.62	1.71	11.34	10.00	Fusel oil	.50+2.50	18.34	1.71
		20.00	132.40		Feed	.50+4.63	137.27	20.00
		5.00	33.10			.50+1.25	31.35	5.00
Raisins, dry	1.14	9.51	10.84	9.00	Fusel oil	.50+1.00	18.34	9.51
		20.00	22.80		Feed	.50+1.75	29.55	20.00
		40.00	45.60			.50+4.00	50.10	40.00

[1] Based on average crop yields, average fermentable content, and 85-percent recovery of alcohol. (See tables 2, 3, and 22.)

[2] Estimated. Undenatured alcohol in storage tanks. Includes all production expense except cost of malting, but no profit is included.

[3] Based on whole slop recovery. No carbon dioxide or miscellaneous credits are included. The price of feed is considered the same as the price of the original raw material less $1.50 for handling, except that for very low priced crops the value is set at $10.00 per ton. The credit for fusel oil remains constant.

[4] For each raw material these are, in sequence: (1) The relative value, per bushel or per ton, which could be paid to compete with blackstrap molasses at 5 cents per gallon; (2) the cost calculated at 1 cent per pound; and (3) the cost, either higher or lower than the (1) figures, which might be reached in commercial markets or which represent a compromise on the (1) figures when they are impractical.

[5] Cost of malting is not included because of the additional complexity it would introduce into the table. On the basis of $1 for malt (per 34-pound bushel) used as 10 percent of the raw material (more particularly cereals), additional cost for malt would range from 2 to 4.5 cents per gallon of alcohol, the lower figure being approached as the relative cost of the raw material rises.

From the data in table 24 it is obvious that crop prices would have to be reduced, unless savings on alcohol processing costs could be accomplished to a degree that does not now seem very likely. These tables are intended to reflect the situation that would obtain on the basis of a large alcohol motor-fuel industry, and the several values may of course be exceeded by single, well-situated local plants which

are unhampered by competition in raw-material purchases and alcohol sales. A very large industry would not necessarily be concerned with molasses-comparison figures, considering the limitation on the available amount of molasses.

HIGHER ALCOHOLS

Theoretically, certain higher alcohols should be better automotive fuels than ethyl alcohol because of their greater carbon and hydrogen content and, consequently, higher fuel value. The ability of these compounds to blend with gasoline, as well as other factors, is sometimes superior to that of ethyl alcohol. Since these materials also may be produced from carbohydrates by fermentation, consideration should be given to the possibility of producing them from farm products.

A great many organisms are known to form butyl, propyl, and perhaps amyl alcohols, and might be available for the production of such materials on a commercial basis. The basic patents on the Weizmann (or original butyl-acetone) process (*82*, *83*) have now expired, and certain other similar strains of bacteria seem to be available without patent limitations, as most patents now in force deal with process applications, improvements, or equipment. The principal difficulty of producing higher alcohols would probably not be patent restrictions. The real problem is the necessary use of pure cultures and the strict procedure which must be followed if adequate yields are to be secured. In a simple yeast process contamination of the fermentation is less important, and a mixture of yeast strains may be used. Such fermentations may usually be exposed to the air without too much adverse effect on yield, while at the same time comparatively high concentrations of sugar may be used. But in a typical clostridium (butyl acetonic) fermentation a relatively dilute sugar solution must be fermented and pure culture conditions rigidly maintained. This entails the use of closed-top fermenters of larger capacity, continuous sterilization of all lines and idle equipment, presterilization of mash, and other items which make the expense greater than that of a yeast process. Furthermore, the product is a mixture (usually of normal butyl alcohol, acetone, and ethyl alcohol) of varying proportions, presenting certain refining problems. The gas evolved in the fermentation contains hydrogen in addition to carbon dioxide.

Heretofore, the only use of this process has been to provide organic solvents, which are usually marketed in a high state of refinement. The process might be simplified considerably for producing a mixed (or unseparated) product for direct use as fuel, or for secondary use as a blending agent in 95-percent ethyl alcohol-gasoline mixtures, the ethyl alcohol being produced by the usual yeast fermentation. This has never received commercial trial, although one alcohol plant is understood to have attempted partial denaturation of the ethyl alcohol by mixing a small proportion of butyl fermentation beer with the regular yeast-fermentation beer. In this case the formula of the finished product called for certain amounts of butanol and acetone.

Products of Butyl Fermentation

In butanol fermentations both hydrogen and carbon dioxide are produced. The usual proportion is 45 percent of hydrogen to 55 percent of carbon dioxide (by volume), but it may be 33+ percent of hydrogen and 66+ percent of carbon dioxide. About 18.2 pounds of mixed gas is produced from a bushel of corn (56 pounds) (containing 67 percent of starch or 37½ pounds of fermentable matter). From this fermentation about 1½ to 2 gallons of mixed solvents are recovered, in the proportion of *n*-butyl alcohol, 60; acetone, 30; and ethyl alcohol, 10 (assuming that 35 percent of the starch is recovered as solvents). In addition, about 1½ pounds of corn oil, 2 pounds of oil cake, and 12 pounds of gluten feed per bushel might be recovered.

Assuming that 48.6 pounds of mixed gas is obtained from 100 pounds of starch (2.664 bushels of corn) and that the gas contains carbon dioxide and hydrogen in the proportion, by weight, of 2,420 to 90, the yields would be 46.85 pounds of carbon dioxide and 1.75 pounds of hydrogen. On a volume basis, however, about 382.9 cubic feet of carbon dioxide and 312.4 cubic feet of hydrogen would be evolved. About 33 pounds of mixed solvents would also be produced (19.8 pounds of butanol, 9.9 pounds of acetone, and 3.3 pounds of ethanol). From a ton of corn the expected yields would be 443 pounds of mixed solvent (63½ gallons), 630 pounds of carbon dioxide (5,130 cubic feet), 23.5 pounds of hydrogen (4,186 cubic feet), 53.6 pounds of corn oil, 71.6 pounds of oil cake, and 430 pounds of gluten feed.

Under the above assumptions 1 mol of glucose would yield approximately 35.7 g of butanol, 17.8 of acetone, 5.94 of ethanol, 84.3 of carbon dioxide, and 3.15 of hydrogen. The heat energy of 1 g-mol of glucose is 677.2 kg-calories, while the total heat energy from the butanol, acetone, ethanol, and hydrogen obtained from the mol of glucose is 587 kg-calories. There is an indicated loss of 90.2 kg-calories, or 13.3 percent of the total heat energy available in the original glucose, which is mostly attributable to the carbon dioxide.

Costs of recovery of feed byproducts from the more dilute mashes used for producing higher alcohols would be greater than with yeast fermentations because of the greater evaporation required. Degermination of the grain might be necessary for satisfactory operation.

Anhydrous Alcohol Compared With Blends

Refining alcohol to the anhydrous stage for use in blending with gasoline may be unnecessary. Anhydrous alcohol has been used heretofore because of the necessity of employing a product that would mix with gasoline in all proportions and remain mixed at all temperatures. Alcohol of lower concentration will function thus only when special blending agents are used. This dehydration step entails a capital investment in special, somewhat-expensive, and complicated apparatus and possibly the payment of royalty on privately patented processes or apparatus. Most of the anhydrous alcohol manufactured in the United States is produced by azeotropic distillation, using benzol. The benzol is recovered and purified for re-use, in the present equipment for this process, which is usually built to insure the removal of all traces of benzol from the alcohol for industrial and beverage grades. But, since benzol may be advantageously allowed to remain in motor-

fuel alcohol, and, since under certain conditions water itself may possibly have a beneficial effect when present in small quantities in the fuel of an internal-combustion engine, refining the alcohol to the present benzol-free anhydrous stage may be an unnecessary expense. Besides labor and overhead costs and shrinkage in volume, about 15 pounds of steam may be required per gallon of alcohol dehydrated, so that in large operations the process cost from 95- to 100-percent alcohol is 0.75 cent or more per gallon.

Butyl alcohol, for example, is perhaps a better fuel than ethyl alcohol, and the increased cost of using this compound as a blending agent might be largely offset by the other gains. Since even 95-percent alcohol blends more or less satisfactorily with gasoline in the presence of sufficient blending agent, it would seem more logical merely to increase the percentage of blending agent and eliminate the dehydration step entirely. The resulting mixture would probably be a better, more balanced fuel; at the same time the presence of these alcohols would safeguard more satisfactorily against possible diversion of the motor-fuel alcohol to beverage purposes.

By eliminating the conventional dehydration operation it may be possible to reduce refining-column requirements to simple or relatively inexpensive designs. In certain modern columns, and perhaps by vacuum or pressure distillation, concentrations higher than 95 percent, even approaching 99 percent, may be achieved by simple distillation.[16]

Even if anhydrous alcohol is used in an alcohol-gasoline mixture, any slight addition of water to the mixture would tend to reduce the blend to the same status as if a 95- to 99-percent alcohol had been originally used. For precautionary purposes, therefore, excess blending agents must be added even when anhydrous alcohol is used. Under favorable conditions, at subnormal temperatures, water may even be removed from blended mixtures made from nonanhydrous alcohol by a large excess of blending agents, or even by gasoline itself. The use of anhydrous alcohol without blending agents instead of 95-percent alcohol and blending agents depends upon eventual relative cost. The present market price of a suitable acetone-butyl alcohol blending agent approximates 53 cents per gallon, but the cost involved in simultaneous production of the blending agent in the motor-fuel alcohol plant would be considerably less. Assuming the use of blending agents in the amount of 10 percent of the total 95-percent alcohol used, if such blending agents could be produced at 30 cents a gallon, a 3-cent cost per gallon of alcohol would be indicated, as against a 2-cent cost for producing the anhydrous alcohol. Considerable research would be required to determine the practicability of the above assumptions.

Gasoline is a variable mixture of many hydrocarbons, the several constituents of the mixture differing considerably as to water tolerance.[17] Different gasolines, therefore, would require individual study

[16] Private communication from the Lummus Co.

[17] In a private communication, G. T. Reich (Pennsylvania Alcohol Co.) reports the following results in mixing four commercial gasolines with alcohol in various concentrations at ordinary temperatures. These gasolines absorbed an average of 6.9 percent of 95-percent alcohol and barely 10 percent of 96.5-percent alcohol. This is probably the minimum effective strength of alcohol which could be commercially used without the use of blending agents. When 97.5-percent alcohol was used, from 1 to 1.6 volumes of gasoline (per volume of alcohol) could be mixed. According to Bridgeman and Querfeld (*15*) critical solution temperatures for a 10-percent alcohol blend with gasoline (without blending agents) are as follows: 95-percent alcohol=52.9°C.; 96-percent=39.4°; 97-percent=22.3°; 98-percent=0.8°; 99-percent=−26.4°. These constants are for the poorest blending gasoline tested, the better gasolines showing about 10° lower separation points.

and treatment as to the use of blending agents. Ormandy (*53*) shows that isopropyl alcohol (producible by synthesis from petroleum gases) has the best water tolerance with certain specific hydrocarbons usually present in gasoline, while in this respect a mixture of ethyl and isopropyl alcohols (10–90) slightly exceeds isopropyl used alone. Benzol and toluene mix well with gasoline, while acetone appears to be poorer than ethyl alcohol itself. Normal butyl, normal propyl, and isobutyl alcohols closely resemble isopropyl alcohol. The water tolerance of blends usually increases as the percentage of ethyl alcohol in the mixture increases, a low concentration of alcohol in the blend causing the greater difficulty with separation resulting from insolubility.

Much experimental work would be required to explore the possibilities in this field. The ideal blending agents should also be effective denaturants and should improve the fuel characteristics of the blend.

Bridgeman (*14*) expresses the opinion that: "By employing ethyl alcohol almost free from water, use of about 5 percent of one of the higher alcohols as a blending agent would probably permit car operation under most conditions without danger of the alcohol separating from the gasoline." He also contends that the higher alcohols are approximately twice as effective as benzene or toluene in raising the water tolerance in blends of gasolines with 10 percent of ethyl alcohol (*14*).

ETHYL ALCOHOL AS A MOTOR FUEL

There has been much controversy as to the value of ethyl alcohol as a fuel for internal-combustion engines, as compared with gasoline. The published data on many angles of performance are frequently inadequate because of failure to take into consideration the influence of all other possible factors and variables on the test. Results of bench tests, wherein all factors are controlled, may contradict road tests, which represent a large number of uncontrolled factors. On the basis of available combustible matter, gasoline is a better fuel for engines of present design than alcohol, since high-test gasoline may contain 135,000 B. t. u. (heat units) per gallon as compared with only 84,425 for alcohol. The low absorption of water by gasoline, in contrast to the miscibility of water and alcohol, is a further advantage. However, certain physical characteristics of alcohol are more favorable. Many claims as to the superiority or inferiority of alcohol have been made. Several of the principal points concerning the use of alcohol blends on which there has been controversy are discussed below.

In table 25 the physical characteristics of a number of possible fuel components have been assembled from various sources.

TABLE 25.—*Physical properties* [1] *of alcohols, hydrocarbons, and miscellaneous organic substances*

Material	Molecular weight	Freezing point	Boiling point	Flash point	Vapor pressure at 86° F. (30° C.)	Specific gravity at temperature given		Solubility (per 100 cc water) at temperature given		Latent heat of vaporization at temperature given		Heat of combustion			Octane number
		°F.	°F.	°F.	*Mm/Hg*		°F.	*Grams*	°F.	*Gram-calories per gram*	°F.	*Kilogram-calories per gram mole*	*Kilogram-calories per gram*	*B. t. u. per pound*	
Acetone	58.05	−138	119	0	277	0.7930	68	∞		134.74	32	423.3	7.29	13,122	
n-Amyl alcohol	88.11	−109	280	104	<10	.8140	68	3.28	71.6	120.17	268	794.5	9.02	16,236	
n-Butyl alcohol	74.08	−129	244	111	11	.8110	68	7.9	68	141	244	638.2	8.61	15,498	
Ethyl alcohol	46.05	−174	173	65	78	.7910	68	∞		236	32	328.0	7.12	12,816	[2] 90
Methyl alcohol	32.03	−143	148	52	160	.7930	68	33.3	−4	284	32	169.3	5.29	9,522	
Isopropyl alcohol	60.06	−129	180	67	60	.7860	68	∞		141	180	475.4	7.92	14,256	
Aniline	93.06	21	364	160	<10	1.0390	32	3.54	77	104	32	810.5	8.71	15,678	
Diethyl ether	74.08	−177	94	−52	647	.7363	32	7.42	68	94	32	644.7	8.70	15,660	
Gasoline, A–2 [3]	[4] 114	<−60	115–389	<0	[5] 284	.7378	60	.004	60	71	250	1,282.5	11.25	20,250	[2] 48.4
Gasoline, B–2 [3]	[4] 115	<−60	111–359	<0	[5] 290	.7563	60	.004	60	70	250	1,286.8	11.19	20,142	[2] 68
Gasoline, C–6 [3]	[4] 94	<−60	122–316	<0	[5] 331	.7117	60	.004	60	72	250	1,065.0	11.33	20,394	[2] 76
n-Butane	58.08	−211	31	Gas	2,554	.6010	32	([6])		91.5	32	677.3	11.66	20,988	[7] 71
Cyclohexane	84.09	44	177	−1	121	.7970	32	([6])		86	32	937.8	11.15	20,070	[7] 84
Benzol	78.05	42	176	<6	118	.9000	32	.073	71.6	107	32	781.5	10.01	18,018	[7] 88
n-Heptane	100.12	−131	205	25	58	.7000	32	.005	59	90	32	1,149.0	11.48	20,664	[7] 0
n-Hexane	86.11	−140	156	0	183	.6770	32	.014	59	91.1	32	989.9	11.50	20,700	[7] 23.5
Naphthalene	128.06	176	424	187	<5	.978	32	.004	77	75.50	392	1,237.4	9.66	17,388	
n-Octane	114.14	−70	258	63	18.4	.7185	32	.002	60	89.4	32	1,302.5	11.41	20,608	[7] −13
n-Pentane	72.09	−202	97	0	615	.6454	32	.036	60	9,315	32	833.6	11.56	20,808	[7] 57.5
Isopentane	72.09	−257	82	<0	819	.6198	68	([6])		93	32	833.6	11.56	20,808	
Toluol	92.06	−140	231	45	37	.8845	32	.047	60	86.5	231	934.3	10.15	18,270	[7] 102

[1] Data have been reduced to comparative bases.
[2] C. F. R. motor method.
[3] Properties of secondary-reference fuels prepared by the Standard Oil Development Co.
[4] Estimated.
[5] Reid vapor pressures.
[6] Insoluble.
[7] Blending octane numbers at 300° F.

MILEAGE

It is claimed that the use of straight alcohol or alcohol blended with gasoline would result in lower relative mileage and power output, as compared with straight gasoline. Because of the lower calorific value of alcohol, the claim is undoubtedly true for straight alcohol and might be uncontrovertible for blends (up to 20-percent alcohol content) if the efficiency of present combustion engines were such as to utilize the potential power of the fuel. But this is not the case. The actual power and mileage output of an engine is the result of such variables as compression, carburetor setting, spark adjustment, engine temperature, volatility of fuel, rate of forward motion, and design, all of which are complicated by traffic conditions, methods of driving, head or tail winds, weight of car, tire traction, road composition and grade, and other uncontrollable factors. A summation result is reached as these various factors combine. Since commercial gasolines are not standardized in composition and since the various makes of cars use different designs and sizes of engines, different carburetion systems, and various degrees of compression, the over-all power production from ordinary gasoline varies, not only between the various makes of car but also between the various trade gasolines. This variation is probably as great as the variation that would result from the use of a low-percentage alcohol blend.

Extensive data have been published on the subject of mileage. Bridgeman (*14*) has summarized the various findings on the use of blends in comparison with straight gasoline and expressed the opinion:

> When used in the same engine, particularly with the carburetor and spark set for the mean of the optimum values for the two types of fuels, little difference in power, acceleration, or fuel consumption is observed with a 10-percent blend, or even with a 20-percent blend under many operating conditions.

He states further:

> If suitably designed engines are used for the two types of fuels, equal or better power and acceleration per gallon of fuel consumed may be obtained from the blend when comparing a gasoline and the same gasoline blended with ethyl alcohol, within the range of present day gasolines.

Ogston (*51*) and Nash (*50*) support these opinions.

The most unfavorable findings (*30*, *43*) claim only from 2- to 4-percent excess fuel consumption with a 10-percent alcohol-gasoline blend. As far as practical results are concerned, there may be as much difference as that today between any two commercial gasolines purchased at adjoining service stations, and since this difference represents only about one-half mile per gallon of fuel,[18] it might not be important to the average motorist. The findings of Egloff and Morrell (*30*) agree with those of Ross and Ormandy (*59*), who in a study of fuel consumption at variable motor loads (bench tests) found that with 10-percent alcohol-gasoline blends the fuel consumption under quarter load was 2.4 percent higher, with half load was 3.0 percent higher, and with full load was 1.7 percent higher for the blend. An average of all loads showed the fuel consumption to be 2.3 percent higher with the blend. From tests on alcohol blends and straight gasoline, Lichty and Phelps (*42*) conclude:

> Based on fuel consumption, ethyl alcohol should cost less than gasoline to warrant its use in 10- and 20-percent blends in engines with optimum compres-

[18] MOYER, R. A., and PAUSTIAN, R. G. THE USE OF ALCOHOL IN MOTOR FUELS. Iowa State College 11 pp. 1933. (Mimeographed.]

sion ratios for present "standard" gasolines; it should cost about the same as standard gasoline if both the blend and the gasoline are used in engines with optimum compression ratios suitable for each of the fuels; and the blends should cost less than gasoline with sufficient tetraethyl lead to permit operation in engines with optimum compression ratios for the blends.

Future designs for automotive engines using higher compression ratios, which are admittedly more advantageous to alcohol-gasoline blends than to straight gasoline, may tend to offset the apparent higher alcohol-gasoline blend fuel consumption of the present automotive engine.

ENGINE STARTING

Some investigators have reported poor starting characteristics of certain alcohol-gasoline blends, occasionally noted in cold weather, as being wholly due to the presence of the alcohol. The volatilizing temperature (boiling range) of commercial gasoline is 100° to 400° F., while that of ethyl alcohol is practically constant at 173°. It is a general commercial practice of gasoline companies to market a more volatile gasoline during winter months, especially in cold climates. Bridgeman (*14*) stated:

> When comparing gasolines with the same gasolines containing 10 percent of ethyl alcohol, engine starting will be easier with the blend at temperatures above 0° F. and will be more difficult with the blend at temperatures below −10° F., with little difference in the intermediate range. The conclusions are not changed when the blend has the same vapor-locking tendency as the gasoline.

His conclusions were based on the use of a straight alcohol-gasoline mixture without blending agents and with no separation of alcohol from the gasoline. In starting (*14, 50*) at temperatures above 0°, the 10-percent blend permits starting with lower fuel consumption than does gasoline, whereas the reverse is true at lower temperatures. Relatively the same ease of engine starting can be obtained at low temperatures by using more volatile gasolines for blending, but this may require improvement in the fuel systems in order to eliminate the increased vapor-locking tendency of such blends at warmer temperatures. The use of satisfactory volatile blending agents with alcohol-gasoline mixtures in winter in cold climates would accomplish the same results and would be in line with the present policy of the petroleum industry. To some extent alcohol might form azeotropic mixtures with certain of the gasoline components. Such azeotropes would distill below the boiling points of either the alcohol or the gasoline (*74*).

VAPOR LOCK

Vaporization of a fuel in the feed lines causes loss of engine power, poor acceleration, and, in extreme cases, engine stoppage. In modern cars the gasoline is drawn from the storage supply tank, usually located in the rear of the car, either by a vacuum induced by the piston action of the engine or by a fuel pump. In either case the vapor-air mixture for each explosion is drawn by suction from the carburetor into each cylinder. The application of vacuum to fuel lines lowers the relative boiling point of the fuel, and under certain conditions, especially heat, a highly volatile fuel may vaporize in the feed lines and reduce the amount of liquid flowing to the carburetor, thus causing irregular engine operation. This phenomenon is known as vapor lock. Among the factors involved in vapor lock are volatility of fuel, temperature of the feed lines, and capacity of the fuel system for handling

vapor. A highly volatile gasoline, designed for easy starting in winter weather, has a tendency to vapor lock if used in the fall or spring, when both warm and cold days are likely to occur.

Alcohol has a higher boiling point (173° F.) than the usual initial boiling point of gasoline (100°–125°) and is, therefore, slower in vaporizing in the feed line or carburetor system.

Bridgeman (*14*) concludes:

> When used in the same engine, a 10-percent blend is more likely to give trouble from vapor lock than the gasoline (alone) with which the alcohol is blended. Little difference would be expected with a 20-percent blend, and the situation would be reversed with a 40-percent blend, since there is greater freedom from vapor lock difficulties with the blend than with the gasoline from which the 40-percent blend was prepared. Addition of alcohol in increasing quantities first increases and later decreases the Reid vapor pressure.[19] The same [comparative] freedom from vapor lock may be obtained for a 10-percent blend and gasoline if the vapor pressure of the gasoline used [for blending] is lower than that of the gasoline with which the blend is compared.

COMPRESSION RATIOS

It is generally admitted (*14*, *50*, *51*) that the use of ethyl alcohol or ethyl alcohol-gasoline blends as fuel permits the use of a higher compression ratio than does the same unblended gasoline. Lichty and Ziurys (*43*), in a comparison of engine performance (single-cylinder test engine) on gasoline and 190-proof ethyl alcohol, state: "Compression ratios as high as 7–1 could be used with the C. F. R. engine [20] when using the treated standard gasoline; no detonation was observed using 190-proof alcohol with a compression ratio of 8:1." Bridgeman (*14*) believes "No material gain in engine performance is obtained by the increase in octane number on blending unless the compression ratio of an engine is sufficiently high to take advantage of the increased octane number." Ogston (*51*) and Nash (*50*) concur in the above opinions. Recent engines seem to tend toward a higher compression, some passenger cars now using ratios as high as 6.7 to 1 for standard models, with optional compressions of from 7.0 to 7.45 to 1. It may be expected that engine design and suitable fuel will develop in relation to each other. As a limiting factor, the increase in number of piston rings or the tighter fit required with higher compressions may introduce frictional losses offsetting power gains from the fuel. Heavier cylinder walls are required with higher compressions and entail increased engine weight and cost.

OCTANE RATING

The actual worth of the octane rating test of a fuel has of late been perhaps overemphasized. This rating is merely a comparison of an unknown fuel with a standard fuel under an arbitrary set of assumed conditions by which the over-all effect of road-test conditions can be measured relatively, at least for gasoline. The test conditions are such that it is possible to secure duplicate results for the mixtures of hydrocarbons sold as commercial gasoline, but the same test conditions applied to entirely different substances may give incorrect relative values to such substances (more favorable for benzol and less so for alcohol).

[19] Reid vapor pressure refers to a method of test known as the Reid method. It has been standardized by the American Society for Testing Materials, Serial D323–32T.

[20] An engine developed by the Cooperative Fuel Research Committee. It is designed to give reproducible test results when used in a prescribed manner. In the case of gasoline, such results approximate road-test figures.

The effect on the octane rating of gasoline resulting from the addition of ethyl alcohol is summarized in the following statement by Bridgeman (*14*):

The octane number of pure ethyl alcohol is about 90 [on the basis of present test methods], while that of gasoline varies from about 74 to 80 for the first grade, about 65 to 70 for the second grade, and usually below 65 for the third grade. Accordingly, blending ethyl alcohol with gasoline will improve the octane number by amounts which cannot be stated quantitatively but which depend upon the percentage of alcohol used and upon the octane number of the gasoline. In general, addition of 10 percent of ethyl alcohol to a second or regular grade of gasoline will increase the octane number about 3 to 5 units, while the increase will be less when blending with the first or premium grade, and may be as high as 10 octane units when blending with a low, third-grade gasoline. As the result of this increase in octane number, it is possible to use for blending, a gasoline of lower octane number than would be used unblended.

Ogston (*51*) states:

It can, no doubt, be accepted that, at any rate with fuels of between 65 and 85 octane numbers, an increase of one octane number will permit an increase of about 1 percent engine efficiency, always provided that the engine has been properly designed to take full advantage of the higher antiknock value. Now, although the alcohol response of different gasolines varies a good deal, as a general rule it can be accepted that when ratings between 65 and 85 octane are being dealt with, the addition of 1 percent ethyl alcohol increases the knock rating of the gasoline by at least 0.7 octane number. * * * Thus a 15 percent blend results in a loss of 5 percent calorific value, but the octane rating would have been increased by at least 10, which will accordingly permit an increase in efficiency of about 10 percent. It is evident from this that alcohol, therefore, more than "pays its way," since its lower calorific value is offset by the higher efficiency which it is possible to obtain by better octane rating in the ratio of loss to gain of about 1 to 2. The inclusion of benzol, of course, still further improves the picture.

Nash and Howes (*50*) state "The antiknock value of ethyl alcohol has been recognized for some years and has not been disputed."

RELATIVE COST OF INCREASING THE OCTANE RATING BY ETHYL ALCOHOL AND BY ETHYL FLUID

There is some question as to the comparative cost of ethyl alcohol and ethyl fluid (tetraethyl lead) as a means of increasing the octane rating. An estimate of such cost is given in table 26, but it must be understood that the relative additions vary for different gasolines and for other octane ratings. In this calculation a base gasoline octane rating of 62 is assumed to be increased to 69 by the addition of alcohol and of ethyl fluid.

TABLE 26.—*Relative cost of alcohol and ethyl fluid in motor-fuel blends*

It is assumed that a base gasoline rating of 62 is increased to 69 by the addition of alcohol or ethyl fluid]

Blend		Cost with alcohol at—		
		15 cents a gallon	20 cents a gallon	25 cents a gallon
Ethyl alcohol, 100 gallons		$15.00	$20.00	$25.00
Gasoline, 900 gallons, at 4 cents a gallon		36.00	36.00	36.00
		51.00	56.00	61.00
Gasoline, 999.6 gallons	$39.98	43.81	43.81	43.81
Ethyl fluid, 1,667 cc	3.83			
Difference		7.19	12.19	17.19
Increase in cost, per gallon of fuel, due to using the 10-percent alcohol blend instead of ethyl fluid		.007	.012	.017

The calculation is based on the assumption that the materials are obtainable at the following costs: Ethyl alcohol (99.5-percent), f. o. b. distilleries, 15, 20, and 25 cents per gallon; base gasoline, 62 octane rating, f. o. b. refineries, 4 cents per gallon; ethyl fluid, f. o. b. blending plant (adjacent to distillery and refinery), $8.70 per gallon, or 0.23 cent per cubic centimeter. One percent of alcohol is required to raise the octane rating 0.7 unit, and 1 cc of ethyl fluid per gallon to raise the octane rating 4.2 units. A 10-percent alcohol-gasoline blend would, therefore, be considered equivalent to gasoline containing 1.67 cc of ethyl fluid per gallon. For the purpose of the computation, it is assumed that the power efficiency of the alcohol is identical with that of gasoline.

The sale value of the blended fuel would probably be 1 cent or more greater than that of the original gasoline, largely offsetting the increased cost due to the use of alcohol.

GREATER SALE VALUE OF ALCOHOL BLENDS

The alcohol used in alcohol-gasoline blends is entitled to credit for increasing the sales value of the mixture. Assuming that a third-grade gasoline (62 or below) which sells for 4 cents at the refinery is increased 10 points in octane rating and thus achieves either a 1-cent or a 2-cent advance in price to 5 cents or 6 cents, respectively, the alcohol used in this mixture could be given the value shown in table 27.

TABLE 27.—*Relative sales value of alcohol in blends of variable composition*

Materials	Valuation			
	Alcohol (14-percent blend)[1]		Alcohol (10-percent blend)[2]	
	1-cent increase	2-cent increase	1-cent increase	2-cent increase
100 gallons of alcohol-gasoline blend at 5 cents per gallon	$5.00		$5.00	
100 gallons of alcohol-gasoline blend at 6 cents per gallon		$6.00		$6.00
86 gallons of gasoline at 4 cents per gallon	3.44	3.44		
90 gallons of gasoline at 4 cents per gallon			3.60	3.60
By difference, 14 gallons of alcohol	1.56	2.56		
By difference, 10 gallons of alcohol			1.40	2.40
Allowable value of alcohol per gallon	.11	.184	.14	.24

[1] Based on the assumption that 1 percent of alcohol increases the octane rating 0.7.
[2] Based on the assumption that 1 percent of alcohol increases the octane rating 1.

If alcohol costs 18 cents a gallon to produce, it is clear that a 2-cent increase in sales value would be required to net a profit on such a blend, particularly in the case of the 14-percent blend. A 1-cent price increase would be a loss. (Equal engine performance is assumed.)

The second calculation assumes that a 10-percent addition of alcohol would raise the octane value of the blended fuel 10 units, which seems to be possible in some instances. A marked increase in the relative alcohol values, over the 14-percent blend, is exhibited. These values indicate some possibilities for the use of alcohol as a means of raising the octane rating, at least with certain gasolines.

ENGINE TEMPERATURE

The latent heat of vaporization of ethyl alcohol is 209 calories per gram, as compared with about 75 calories per gram for gasoline. The boiling temperature of ethyl alcohol is approximately 173° F., while that of gasoline ranges from 100° to 400°. When using a fuel containing ethyl alcohol (*50*), an engine operates more efficiently at a cooler temperature than when using ordinary gasoline. Ogston (*51*) states that when using a motor fuel containing tetraethyl lead a high temperature of operation produces a greater degree of efficiency, while with alcohol greater efficiency is obtainable at a much lower temperature. Ogston (*51*) and Nash (*50*) suggest that alcohol-gasoline fuels show to disadvantage in comparison with gasolines containing tetraethyl lead in the Cooperative Fuel Research Committee test engine because of the conventional preheating of the gaseous fuel before entering the reaction chamber. In road tests, the alcohol-gasoline blends (of the same octane rating by the C. F. R. method) show a higher efficiency.

Because of the lower flame temperature, higher latent heat of vaporization, and smaller air dilution under running conditions, alcohol-gasoline blends should develop a lower engine temperature than gasoline.

SEPARATION OR STABILITY OF BLENDS

Nash and Howes (*50*) state that alcohol motor fuels in actual practice are not freely exposed to the atmosphere and, as a result, can be used with satisfaction. Ogston (*51*) points out that a gasoline blend containing 15 percent of anhydrous alcohol and 15 percent of benzol will stand a 1-percent dilution, that is, water in excess of 50 gallons would be required to cause separation of 5,000 gallons of the blend. About 5,250 cubic feet of saturated air at a temperature of 80° F. is required to hold 1 gallon of water. If the temperature is reduced to 30° about 0.75 gallon of water is precipitated (*74*). The water precipitated from about 300,000 cubic feet of saturated air would, therefore, be necessary to cause separation in a 5,000-gallon tank. Christensen, Hixon, and Fulmer (*20*) in a discussion of time exposure and water absorption state that "the more nearly the experimental conditions approached those of actual commercial storage, less water is absorbed * * * with reference to storage of a 10-percent blend in commercial tanks no water was absorbed * * * in 66 days." Hubendick (*36*) reports no trouble from water absorption during 10 years' commercial use of blends in Sweden. Undoubtedly precautions against direct water contamination would have to be taken in the handling of alcohol blends, but with proper care little actual trouble probably need be anticipated, and certainly none from mere atmospheric contact.

SOLVENT ACTION

Fears have been expressed as to probable trouble from the solvent action of alcohol-gasoline blends on automobile finishes (*30*) and on the shellac of carburetor floats; and from the loosening of scale deposits in fuel tanks and lines, with subsequent deposition on carburetor screens, etc., causing plugged fuel lines.

Admittedly, an alcohol-gasoline blend containing 20 to 35 percent of ethyl alcohol would possess greater solvent properties and would

therefore endanger present-day automobile finishes more than the lower concentration blends or unblended gasoline. However, Scales (*60*) and Nash and Howes (*50*) state: "Many of these difficulties met with in using 20 to 35 percent alcohol blends probably would not be serious in the case of the 2 to 10 percent blends proposed in the United States." Because the new resins now being incorporated in automobile finishes are less soluble in alcohol than the lacquer formerly used, the damaging of automobile finishes is less likely to occur. The use of higher alcohols or acetone as blending agents would of course increase the danger to lacquer finishes. Varnish would be likely to show blush marks even under the action of dilute alcohol. However, the use of alcohol antifreeze solutions presents the same problem, and these solutions are usually far more concentrated and more likely to come into accidental contact with the car finish, except in cars of recent model, in which the radiator fill pipe is beneath the hood.

Removal of shellac from carburetor floats is no longer much of a factor because metal floats are now used in most modern cars.

Changing from straight gasoline to an alcohol-gasoline blend has frequently caused scale stoppage in the fuel lines; however, continuous use (*50*) of the alcohol-gasoline blend caused no further stoppage. No stoppage would be likely to occur if a new car were started with, and continued to use, an alcohol-gasoline blend of approximately uniform composition. Ogston (*51*) suggests that synthetic rubber be substituted for natural rubber in making hose for dispensing stations because of its greater probable resistance to the action of solvents.

CORROSION FROM ALCOHOL BLENDS

Instances of engine corrosion caused by alcohol blends have been reported. It is contended, however, that in most of these cases impurities (*14, 50, 51*) in the blending agent were responsible rather than the alcohol. A particular instance of such impurities is sulphur in benzene. In foreign countries corrosion has been attributed to acids formed by the combustion of some blending agents, such as ethyl ether. Bridgeman (*14*) is of the opinion that

> with high percentages of alcohol in the blend, and without the presence of blending agents, the amount of acetic acid formed on combustion may cause corrosion of the exhaust manifold and muffler. Corrosion difficulties probably can be minimized by the proper selection of blending agents and by the use of suitable corrosion resistant materials in the exhaust system and in storage containers.

Certain denaturants used in the alcohol-denaturation formulas may be potential sources of corrosion, but considerable study would be necessary to confirm this presumption. Cases of corrosion of the muffler system where leaded or even straight gasolines were used as fuel have occurred, the exact causes being unknown.

ARBITRARY BLEND PERCENTAGES

In any consideration of alcohol-gasoline blends, the question arises as to what proportions should be adopted as a standard. In the United States the use of ethyl alcohol in motor fuel has been advocated principally on the basis of the economic utilization of farm surpluses and conservation of natural resources. Although larger proportions, 15 to 20 percent, of alcohol in fuel blends would have more effect on conservation of petroleum reserves, at present, production of the

requisite quantities of alcohol would be impossible. In any case the loss of mileage and consequent increased expense of operation of present cars would militate against the use of such concentrations.

The other extreme, for example a 2-percent blend, would result in practically no conservation of resources, and the behavior of such a low percentage blend in the average motor would be relatively poor because of the small increase in octane value. In addition, this small amount of alcohol would be uneconomical because of the lower fuel value introduced. Thus all the disadvantages of alcohol would be incurred without any compensating advantages.

A 5-percent blend more nearly approximates a balance, and blends of approximately 10 percent may achieve a balance wherein the interrelation of all factors tends to present optimum over-all results. In general, a 10-percent blend has been assumed in this discussion, unless otherwise indicated.

ECONOMIC ASPECTS

RAW MATERIALS OTHER THAN AGRICULTURAL PRODUCTS

NATURAL RESOURCES

At present automobile fuel in the United States is practically limited to petroleum. Because of the rate at which our petroleum resources are being used, some concern is felt for the future, and the petroleum industry itself is giving thought to replacement fuels. The future motor-fuel requirements of the United States, as estimated by the American Petroleum Institute (7), are shown in table 28. As wood (cellulose), coal, shale oil, and natural gas are possible sources of new fuels, an evaluation of these sources is necessary in order to determine how far agricultural raw materials may be expected to stand competition with them.

TABLE 28.—*Future motor-fuel requirements* (7)

Year	Total demand	Available from—		Estimated fuel consumption per automotive unit	Estimated total vehicles registered
		Benzol and natural gasoline	Crude petroleum		
	Barrels [1]	*Barrels*	*Barrels*	*Barrels*	
1940	563, 880, 000	45, 000, 000	518, 880, 000	17. 38	29, 200, 000
1950	636, 570, 000	47, 000, 000	589, 570, 000	16. 90	33, 900, 000
1960	657, 490, 000	48, 000, 000	609, 490, 000	15. 95	37, 100, 000

[1] 42 gallons each.

All our natural resources have suffered waste and rapid depletion, and all of them except wood are irreplaceable; therefore, even were it possible to produce motor fuel from some of these sources at a lower price than they can be produced from agricultural sources under present conditions, they would eventually be exhausted. A period of 30 to 50 years is not much in the lifetime of a nation. What will the situation be in another 50 years? The last half century has witnessed the conversion of a vast amount of natural resources to actual money values. The exhaustion date of these resources cannot be predicted, but a gradual advance in price may be anticipated as the better or more easily available supplies are used up.

A résumé of the present status of fuel resources follows.

Petroleum

It took from 1857 to 1900 to produce the first billion barrels of crude petroleum in the United States. More than that amount is now produced in 1 year. Present petroleum reserves are authoritatively estimated to be from 10 billion to 15.5 billion barrels.[21] Unless new sources of oil are discovered, therefore, the supply would be virtually exhausted in perhaps 15 years under present rates of consumption, if it were possible to produce it at the same rate as the supply decreased. But such a prediction is somewhat meaningless as far as the use of alcohol as a fuel is concerned, since shortage actually begins when prices begin to climb, and price advances would affect consumption of both straight and blended fuel to an unpredictable degree (*63*).

The average depth of wells has been increasing, a 12,000-foot depth (approaching the lowest known oil-sand strata) having become a commonplace in the past few years. Several wells are now producing from the 11,000- and 12,000-foot levels, and a depth of 15,400 feet had been reached by April 1938. An increasing percentage of dry holes was encountered in the period 1923–33 in spite of increased and more accurate geological knowledge (*63*). In Oklahoma the percentage of dry holes ranged from 7 to 20 during the period 1904 to 1917, from 20 to 30 from 1918 to 1924, and from 30 to 35 from 1924 to 1933. In California the percentage was 3 to 12 from 1905 to 1922; 21 to 26 from 1923 to 1930, 49 in 1931, 48 in 1932, and 40 in 1933. In Texas 17 percent in 1919 had risen steadily to 45 in 1930 (*63*). The average number of dry holes (for all wells drilled) for the entire country has been 18 to 20 percent, rising as high as 31.7 in 1928 and 1930. A total of 21,420 new wells were drilled in 1935, of which about 23 percent were dry holes (*8*); 25,888 were drilled in 1936, of which 20.4 percent were dry. The percentage of dry holes, however, is not especially significant, since depth and location of holes as drilled are somewhat a reflection of the economic state of the industry.

The discovery of the eastern Texas field in the fall of 1930 stimulated the exploration for new oil fields. The only major field discovered during this time, however, was the Conroe fields in 1931. Between 1931 and 1935 an average of about 580 million barrels of oil a year was discovered. Development of drilling methods and machinery and improvements in pumping technique are increasing the recoverable reserves. Recently (1935–36) increases have about offset consumption.

Although the decrease in gasoline consumption in the depression years and the restriction of production in some States has had an adverse effect on bringing new areas into production, according to Snider and Brooks (*63*), McIntyre has estimated that 73,000 new wells were drilled between 1930 and 1935. From 1932 to 1936 the United States produced from 60 to 63 percent of the total world production of crude petroleum for that period; in the period from 1857 to 1936 the percentage was 64. Texas, California, and Oklahoma produced 77.3 percent of the national total in 1936 and are

[21] A recent estimate of the American Petroleum Institute claims reserves of 15,507,268,000 barrels (Jan. 1, 1938). This estimate may be partly based on improvements in recovery methods which are applicable to former known reserves. New reserves (for 1937) of 928,742,000 barrels are included in the estimate.

credited with 81 percent of the proved reserves in an estimate (Jan. 1, 1937) of the American Petroleum Institute. Kansas and Louisiana produced 12.6 percent of the national total.

The production of crude petroleum in the United States for various periods from 1859 is shown in the following tabulation:

Period	Barrels[1]	Period	Barrels[1]
1859–75	74, 072, 000	1927–35	8, 154, 494, 000
1876–89	330, 742, 000		
1890–1902	756, 947, 000	Subtotal	17, 595, 040, 000
1903–13	1, 907, 933, 000	1936 estimate	1, 099, 000, 000
1914–18	1, 538, 878, 000		
1919–26	4, 831, 974, 000	Total	18, 694, 040, 000

[1] A barrel is computed as 42 gallons.

Demand for domestic motor fuel increased to 481,591,000 barrels in 1936, which was 10.8 percent over the demand in 1935. This is about 18.71 barrels for each motor car in use (*37, p. 1028*). The United States per capita consumption of petroleum products, which is the highest in the world, rose from 4.23 barrels in 1921 to 8.51 barrels in 1936. About 44 percent (weighted average) of the crude oil produced is recovered as gasoline (exclusive of natural gasoline). It is estimated that between 1932 and 1935 a total of 6,111,146,000 gallons of natural gasoline was recovered (*37*).

Although motor fuel today includes that used for aircraft and Diesel engines as well as for automobiles and tractors, in this study consideration is confined to fuel for the ordinary internal-combustion, low-compression ratio engine (carburetor type) used in automobiles, which requires fuel of the nature of present gasoline. Such gasoline is generally classified according to source, as "straight run," "cracked," or natural (formerly "casing head") gasoline.

Straight-run gasoline is a natural, low-boiling fraction obtained in the distillation of crude petroleum. The fraction ranges from 20 to 35 percent of the original crude petroleum, the average being about 23 percent. If taken over wide limits, this fraction is low in volatility and antiknock rating (which is usually about 56). Consequently it is either sold as third-grade gasoline for use in low-compression engines or blended with other grades. Special fractions, or cuts, however, may be very high in octane rating and volatility.

Cracked gasoline is obtained by subjecting heavy crude petroleum oils, topped crude oils (from which the original straight-run gasoline fraction has been removed), or other heavy oils to high temperature and pressures, which break the stock down into gas, gasoline, and heavier fractions. Cracked gasoline usually has high volatility and relatively high antiknock rating (65 to 75). Since 1928 the amount of cracked gasoline produced has been doubled. About 50.7 percent of the gasoline produced from petroleum in the United States in 1935 was cracked, and 49.3 percent was straight run. This is equivalent to a 44.1-percent recovery of gasoline from the total original crude petroleum. Different fields, of course, yield different figures. As purchased, a trade-marked gasoline may be a mixture of products obtained from several petroleum fields, and separated or formed by different methods. These mixtures are approximately uniform in price and in behavior in average cars. Blending fractions for high-octane fuels are now principally recoverable from natural gas (so-called natural gasoline or casing-head gasoline) or are obtained by

the polymerization or hydrogenation of waste gases from the cracking process, a great deal of experimentation being now in progress in this field. In 1934 natural gasoline amounted to almost 7 percent of the total gasoline production.

The amount of gasoline of all grades consumed each year since 1930, according to estimates by the Bureau of Public Roads, is shown below:

Year	*Gallons*	*Year*	*Gallons*
1930	14, 751, 309, 000	1934	16, 136, 137, 000
1931	15, 407, 650, 000	1935	17, 160, 339, 000
1932	14, 250, 173, 000	1936	19, 011, 552, 000
1933	14, 224, 321, 000	1937	21, 208, 977, 000

There have been many improvements in the petroleum industry. These have resulted in the recovery of greater percentages of gasoline from the crude petroleum, reduced wastage, and more economic production. Other improvements have decreased the cost of producing oil from the dying pools and located new wells in fields previously thought to be diminishing. At present there is considerable State regulation of oil production, and some progress has been made in controlling the bootleg-petroleum evil.

Out of the mass of data on petroleum, a reliable prediction regarding the duration of the petroleum supply is difficult. It seems probable that the supply of petroleum will not be exhausted for perhaps 50 years. But it can be anticipated that within a decade or so decreasing production, or below-ground scarcity, will force the price of gasoline to considerably higher levels, unless significant amounts of new reserves are discovered.

In the last analysis true conservation of petroleum resources may not involve holding a reserve below ground untouched for future use. Engines developed in the years to come might use some other form of motor power. Conservation at its best seems to be largely a matter of regulation of output to avoid waste and uneconomic prices. Competitive tappings of a common oil pool can lead only to waste and overproduction, unless rigidly regulated on some equitable basis for the common good.

Natural Gas

The natural gas marketed in 1936 (*37*) amounted to 2,175,000,000,000 cubic feet, 1,900,000,000,000 cubic feet of which was treated for recovery of natural gasoline. About 0.9 gallon of natural gasoline is recoverable per thousand cubic feet of gas. A portion of the gas treated for recovery of natural gasoline at petroleum refineries escapes into the air and is wasted, but no estimates are available regarding wastage.

The average value of the gas in 1935 was about 5.8 cents per thousand cubic feet. The average value of natural gasoline is about 4.6 cents per gallon.

The sale of liquefied petroleum gases (butane) is rapidly increasing. In 1936, 106,652,000 gallons was sold, an increase of 39 percent over 1935.

Eventual exhaustion of natural gas may also be expected, since a large amount of this gas is associated in the earth with petroleum or coal. The waste of natural gas has in the past been more serious than that of any other of our natural resources, partly because of the difficulty of controlling it or in bringing it to a market. Much was

wasted previous to the opening of market outlets. Because of the potential danger involved, natural gas must be removed or destroyed when its presence interferes with mining or other operations.

Ethyl alcohol has been produced commercially by synthesis from the ethylene contained in the natural gas from certain areas. The cost of producing synthetic alcohol is probably less than the cost of producing the same alcohol by fermentation.

Shale Oil[22]

On the basis of chemical composition, the oil recoverable from shale rock by distillation may be the most logical successor to petroleum as a source of motor fuel. Shale deposits vary greatly in oil content and composition, but they are seemingly unlimited, and not much progress has been made thus far in the United States toward their commercial exploitation. About 26 experimental plants were listed in 1925 (*47*). The American Petroleum Institute has estimated that 108 billion barrels of oil is potentially available from this source (*7*), but no estimate can be made as to the cost of the oil if produced. A considerable proportion is lost in retorting, as some of the oil is carbonized, yielding gas byproducts. The United States Bureau of Mines has experimented with a shale-oil pilot plant (*33*), but has not succeeded in producing motor fuel at a price that could compete with that from other sources. Assay values of from 15 to 50 gallons per short ton have been secured. Results obtained at a California pilot plant indicate that mining the rock would cost $3.52 per ton, and the gasoline made from it would cost $0.124 a gallon (*81*).

In Scotland, production of shale oil has met with some commercial success, but costs seem to be increasing. The crude shale oil now costs about $3.02 per barrel, or three times the present price of crude petroleum oil (*63, p. 28*). Costs of mining shale rock range from 40 cents to $2.50 per ton. From some selected shale perhaps 22 imperial gallons of oil can be recovered per long ton. The yield formerly was 33 to 36 gallons per ton. From 20 to 60 pounds of gas and ammonia byproducts (ammonium sulphate) per ton are secured from some shales.

Australian torbanite is claimed to yield 75 to 180 imperial gallons per long ton (*17*).

From 1922 to 1937 Esthonia produced commercially about 340,000 tons of crude shale oil. It is now produced at the rate of over 100,000 tons per year. The crude oil recovered amounts to 20 percent of the rock, and the gasoline fraction amounts to 20 percent of the crude oil. The price of the gasoline in bulk has been 32 cents per United States gallon (*5*).

The estimated world production of shale oil in 1934 is shown below (*37*):

	Metric tons		*Metric tons*
Australia (New South Wales)	203	Italy	550
Australia (Tasmania)	3, 329	Spain	37, 783
Esthonia	588, 958	Union of Soviet Socialist Republics	206, 400
France	102, 340	Scotland	1, 423, 257
Germany	869		

[22] United States Bureau of Mines. Review of the petroleum industry of the united states. U. S. Bur. Mines Cir. 11, 50 pp. 1934. [Mimeographed.]

Coal

There is no possibility of the exhaustion of coal for a century or more, although our supply of soft coal of the better grades has been depleted. In the West Virginia fields particularly, certain seams have been mined below thinner seams of less commercial importance. The recovery of the coal in the seams above the excavated area will, of course, be more difficult and expensive. Poorer seams usually contain higher proportions of ash, slate, sulphur, calcium sulphate, iron, and clay. It is difficult to visualize a hydrogenation program for these poorer seams, particularly as far as production costs are concerned, since coal mined in the future will be more expensive than, and chemically inferior to, that mined at present. Coal hydrogenation does not give much promise of motor fuel at costs comparable with the present market price of petroleum fuels. However, the production of alcohol from agricultural materials would necessitate the use of large quantities of coal for conversion and recovery, perhaps up to 11,000,000 tons annually.

Coal consumption in the past is indicated by the following figures (*37*): Total production from earliest records to 1935, exclusive of lignite, 17,689,070,000 short tons of bituminous and 4,129,922,000 short tons of anthracite, a total of 21,818,992,000 short tons. The production in the United States in 1935 was 424,532,000 tons, and the total world production was 1,127,000,000 short tons.

Wood

Of the original dense forest of 820 million acres which constituted the America of 1630, we now have about the following, including the forests of Alaska: Merchantable forest (not all virgin), 150 million acres; cut-over forest (growing), 200 million acres; and cut-over forest (dying), 100 million acres. However, much of this original forest land is now put to better use as cropland.

In a single generation prices have gone from $15 to $85 per thousand board feet. The peak of production was reached about 1907 and since then has declined. In 1928 the United States Forest Service estimated that 68 percent of all wood cut for timber was actually wasted between the forest and the consumer. From 1925 to 1929 the annual cut and waste was 16.3 billion cubic feet, and the annual replacement was 6 billion cubic feet (*75*, *80*). Soft wood was disappearing about eight times as fast as it grew. Hardwood saw timber was being used up at four times the rate of replacement. Logging operations on Douglas fir sometimes left 40,000 board feet per acre as small-log waste. Some of this area is now being relogged with smaller machinery. With a reserve of 1,700 billion board feet and an annual cut of 40 billion board feet, the forests may be practically wiped out in 40 years unless a comprehensive program of replacement is followed.

Recently the trend of consumption has been in the opposite direction, tending to increase the reserves. Use of timber for railroading, housing, construction, etc., has decreased. At present, there is a tendency toward use of replacement materials, particularly in building construction. Fireproofing has encouraged the use of less inflammable materials. Such development has the effect of decreasing consumption, while at the same time timber replacements have been made. Wood resources are not static. Much submarginal cropland might

perhaps effectively be used for tree growth. For chemical raw-material purposes a 15-year tree growth in many regions would be satisfactory. The land is available, and if a need is foreseen an extensive replacement campaign would change the existing situation. Wood, therefore, remains as a future possible source of liquid fuels.

SYNTHETIC MOTOR FUELS

Synthetic chemical compounds obtained from waste gases by pressure catalysis, hydrogenation, pyrolysis, polymerization, etc., constitute suitable replacement motor fuels, and competition with future fuel materials produced from agricultural sources will most likely come from this rapidly expanding field. Much research is now being done on these processes, but because of the rapidly changing status resulting from the flow of new data secured by the many investigators engaged in exploring the possibilities of these sources, very little accurate information on yield or cost can be secured. Not only is petroleum itself a very cheap raw material, with potentialities perhaps as great as those formerly possessed by coal tar, but waste refinery cracking gas and other refinery wastes; coal gas, water gas, and coke-oven gas; natural gas; and similar sources of paraffins and olefines are abundant, and all are susceptible of chemical treatment in several ways. Moreover, the products obtained by various methods of processing are frequently identical, although the respective percentages may vary. Besides these sources, the liquefaction of coal by hydrogenation and the distillation, or cracking, of creosote and tar by-product from wood distillation or low-temperature coal distillation constitute potential competitors of agricultural products as sources of motor fuel.

As the present trend of motorcar design is toward higher engine-compression ratios, it may be anticipated that the production of fuels of higher octane value will increase, with consequent decrease in the output of third-grade gasoline. Most of the synthetic fuels produced from waste gases are notable for high octane values, and many of them are physically very similar to present gasoline fuels and therefore introduce no new problems in engine performance or design.

Products From Olefines

Two of the simpler processes of producing alcohols and alcohol derivatives from gas by synthetic methods have already reached commercial production on a large scale. These are the production of methanol by combination of carbon monoxide and hydrogen and the production of ethanol by absorption of ethylene in sulphuric or other mineral acids, and subsequent hydrolysis. These processes are well established in the United States, and the production cost of the alcohols is probably considerably below that of the alternative processes of wood distillation and sugar fermentation. One of the two plants now producing synthetic ethanol in the United States, using ethylene as a raw material, is believed to have originally used the ethylene present in natural gas; the other probably uses the ethylene recovered from the waste gas from the petroleum-cracking process. It is possible that such ethylene is now obtained by other methods. As an alternate process, the pressure catalytic interaction of steam and ethylene presents possibilities.

These are not the only instances of successful commercial production of synthetic alcohols. Butyl alcohol, probably of synthetic origin, has been imported from Germany for many years. Amyl alcohol is being produced commercially in the United States by the chlorination and hydrolysis of pentane fractionated from natural gasoline (*38*). Isopropyl alcohol has also been commercially produced by acid absorption of propylene obtained from the overhead gas resulting from stabilizing cracked petroleum (*16*). Acetone has recently been marketed in the United States, probably made by the reduction of isopropyl alcohol, which in turn was derived from petroleum gases.

These simpler syntheses from hydrocarbons do not, however, exhaust the possibilities. Methanol, for example, can be made from methane by chlorination and hydrolysis, using the methane of natural gas. It may also be produced from carbon dioxide which is first reduced to carbon monoxide (*24*). Other alcohols or compounds can be synthesized by using the same basic materials and equipment and by the same general process by variations of pressure, temperature, or percentage concentration.

As another development, the paraffin hydrocarbons, methane, ethane, butane, propane, etc., which occur so plentifully in gas, oil, and tar, may be changed to olefines (ethylene, butylene, etc.) by dehydrogenation, pyrolysis, or partial oxidation, and the olefines may then be used as raw material for the processes enumerated above (*16*). These unsaturated olefine hydrocarbons can also be hydrogenated, polymerized by thermal or catalytic means, or combined by vapor-phase pressure catalysis to form compounds similar to the normal constituents of gasolines. Some aromatic hydrocarbons, such as benzol, are also formed (*16*).

It is estimated that the petroleum-cracking units now operating in the United States are producing about 300 billion cubic feet of cracked gas a year. Assuming a yield of 5 gallons of polymer gasoline per thousand cubic feet of gas (*68*), about 1,500,000,000 gallons of motor fuel a year might be obtainable. Claims have been made that from petroleum refinery gases alone there might be produced annually a billion gallons of alcohol or of cheaper and better gasoline substitutes (*7*), and other estimates as high as 9 billion gallons have been quoted on the assumption of complete gas recovery from an expanded petroleum-cracking industry. It has been stated, however, (as of 1933), that the production of alcohols from cracking-plant gas may not be practicable if the gas can be sold for fuel at a reasonable return (*50*). The production of special fuels for airplane use, with octane ratings approaching 100 percent, which was a development of this work on catalytic synthesis, has already reached a world total of 10 million barrels a year (*29*).

Synthetic alcohol production may be limited because of the loss and high recovery cost of sulphuric acid (*16*) and because of the cost of hydrogen. Coke-oven gas is here of importance as a source of hydrogen, since ethylene and propylene can be recovered also, without cost, in the hydrogen liquefaction and recovery (*71*). Some acetylene is also recoverable.

Acetylene, obtainable from waste carbide, also is a source of synthetic aliphatic chain compounds. It is now a commercial source of acetic acid, first being converted to acetaldehyde.

METHANOL

Until about 1925 practically all methanol (wood alcohol) was produced by wood distillation. The introduction of synthetic methanol by Germany revolutionized the entire world situation, as methanol can be produced from carbon monoxide and hydrogen by catalytic synthesis at a price far below the cost of production from wood. Methanol is of interest from two angles, since it now finds extensive employment as a denaturant and also is being used in Germany as a motor-fuel ingredient in place of ethyl alcohol. With the expansion of synthetic methanol production in the United States in recent years, practically all the material produced from wood in the remaining wood-distillation plants has been employed in an impure form as a denaturing material. The industrial alcohol regulations specify that denaturing-grade methanol shall be produced from wood and shall contain a portion of the various congeneric bodies normally produced in the wood distillation, thus eliminating synthetic methanol. Table 29 shows the production of methanol in the United States in 1935, 1936, and 1937.

TABLE 29.—*Production of methanol in the United States in 1935, 1936, and 1937* [1]

Year	Methanol produced	
	Crude	Synthetic
	Gallons	*Gallons*
1935	5,048,720	18,046,929
1936	5,575,038	25,563,742
1937	5,753,595	31,814,046

[1] UNITED STATES BUREAU OF THE CENSUS. PRODUCTION OF METHANOL FOR 1935, 1936, 1937. [Mimeographed.]

As a motor fuel, methanol is inferior to ethyl alcohol, since it yields only about 73 percent (weight basis) of the net heat units of ethyl alcohol. Also, it has poorer blending qualities when used with gasoline (*6*). It has a higher latent heat of vaporization than ethyl alcohol and a lower boiling point. It requires less air for complete combustion (*50*) and consequently has a higher volumetric efficiency. Under certain conditions, however, methanol may show better engine performance than ethyl alcohol. In special fuels it has been used in quantities as high as 40 percent of the fuel mixture, the cost being of secondary importance in such cases.[23] It is used quite extensively as an ingredient of racing fuels.

PRODUCTS OF THE HYDROGENATION OF COAL, TAR, AND CREOSOTE

While it is possible to produce motor fuels from coal, tar, and similar materials by hydrogenation processes, the data thus far available do not indicate that such fuels are likely to be produced as cheaply as by synthesis from gases. Hydrogenation fuels have been developed mostly in England and Germany, and very recently in Italy and Japan. The raw materials mentioned above are of course the obvious sources of replacement fuels for countries having coal deposits in place of oil deposits. Any project that promises to remedy a lack of

[23] Private communication.

essential national resources would naturally be encouraged and heavily subsidized by governments facing the loss of essential outside supplies that would result in a general war. In some countries there is a desire to achieve national self-sufficiency regardless of cost.

In the Bergius process of coal hydrogenation, pulverized coal is made into a paste by using a carrier oil and recirculated with hydrogen under high temperature and pressure. It is claimed that by this process 65 percent (by weight) of the coal is recovered as an oil, 25 percent of the oil being directly suitable as motor fuel. About a ton of additional coal per ton of coal processed is required for fuel, so that actually only about 8 percent of the coal (17.5 gallons of oil per ton) is recovered in liquid form (*56*). At the Billingham, England, coal-hydrogenation plant, gasoline yields of 60 to 70 percent (by weight of coal actually treated) are claimed, with an overall of 4 tons of coal used per ton of gasoline produced (*70*). Production costs of the gasoline are claimed to be about 10 to 13 cents per United States gallon (*66, 72*), without obsolescence or interest charges, but no estimate as to how these costs are arrived at or the amount of Government subsidy involved (understood to be at present about 8 pence per gallon) is available. This plant has a capacity of 150,000 tons of petrol a year. The United States Bureau of Mines is experimenting with a coal-hydrogenation pilot plant in Pittsburgh, Pa. (*4*).

So far as national conservation of fuel is concerned, the use of a large portion of our present liquid fuel supply for motor fuel and heat purposes might be considered uneconomic if later it forced us to create other liquid fuels out of coal by an expensive process. About half the thermal energy of the original coal is lost. The capital costs of a coal-hydrogenating plant are at present extremely high, but these may be somewhat reduced as development proceeds.

In the Fisher Tropsch process (Kogasin synthesis) coal or coke is used as a source of water gas. The mixture of carbon monoxide and hydrogen is purified, additional hydrogen is added, and the combined gas is passed over a catalyst at atmospheric pressure at 200° C. "Kogasin I" and "Kogasin II" are trade names of mixtures of the resulting products, which differ from other carbon monoxide and hydrogen combinations in that they contain hydrocarbons and no alcohols. They vary in constitution with change of reaction factors and catalyst (*66*). This process has advanced to the commercial stage, and there is probably less chance of future lowering of capital or operating costs.

Fisher Tropsch plants are understood to involve higher operating costs than coal-hydrogenation plants and produce fuels of lower relative octane rating. The catalysts seem to be easily poisoned. Petrol from coal hydrogenation may show an octane rating from 70 to 100 (Cooperative Fuel Research Committee method). However, Fisher plants may be economically operated at smaller size, and can also produce byproduct oils which can be processed into lubricants, so that in net cost the Fisher products are probably lower than coal-hydrogenation products.

Low-temperature coal carbonization may yield 2 to 3 gallons of oil and 20 to 25 gallons of tar. The coke may subsequently be used for gas production. The tar and creosote may be hydrogenated, oil yields of 80 to 90 percent being claimed (*66*). Tars from many sources, including wood-distillation tars, might thus be brought into

commercial use. At present very little market can be found for many of these raw tars, partly because of the instability due to the high percentages of unsaturated bodies usually present. The destructive hydrogenation of such materials is, therefore, an obvious starting point for a replacement fuel. The principal difficulty would lie in the rather inadequate supplies of raw materials.

The United States Bureau of Mines has stated: [24]

> Low-temperature carbonization is often cited as the process that will solve the problem of future motor-fuel supply. In this process coal is heated to 450° to 700° C. instead of 1,000° to 1,300°. The tar yields are from 20 to 35 gallons a ton, or two to three times that obtained by high-temperature carbonization. Also, the tar resembles petroleum in some respects. From 1 to 2 gallons of light oil can be scrubbed from the gas, and another gallon or two distilled from the tar, the total yield being from 2 to 4 gallons.
>
> Refining losses would bring the net yield of motor fuel from gas-scrubbing and straight distillation of the tar to about 2.5 gallons a ton, or about the same as is obtained in high-temperature carbonization. However, this low-temperature tar may be subjected to the same pressure-cracking processes that are used for petroleum and thus yield 20 to 30 percent of motor fuel. It is, therefore, reasonable to assume a possible yield of 7 to 12 gallons per ton of coal carbonized at temperatures of 450° to 700° C.

BENZOL

The United States Department of the Interior has reported as follows: [25]

> In coke and gas works about 2.5 gallons of refined motor benzol is obtained by the high-temperature carbonization of 1 ton of coal. The total coal coked in the United States in 1926 yielded 112 million gallons of motor benzol, or 1.02 percent as much as the 11 billion gallons of gasoline produced in 1925. If the entire output of about 500 million tons of bituminous coal in 1926 had been put through by-product ovens the yield of motor benzol would have been only 1¼ billion gallons, or 12 percent as much as the gasoline produced in 1925. Today the motor fuel derived from this source is much less, owing to the decreased demand for coke and coal gas. Obviously coke-oven light oil can never supply more than small portions of future motor-fuel requirements.

The production of benzol in the United States in 1936 was estimated to be 105,086,000 gallons, which in 1937 rose to 117,014,000 gallons (crude, refined, and motor benzol). In Germany benzol production increased from 32,800 metric tons in 1935 to 38,850 tons in 1936 [26] (9,800,000 to 11,600,000 United States gallons).

Gas and Solid Fuels

Recently there has been a great deal of experimentation on the use of solid fuels or compressed gas, as well as gas-generating systems, to replace the usual liquid fuel in mobile engines. It is possible that such fuels can be produced from agricultural products.

In the western part of the United States compressed petroleum gases have been used commercially for operating motortrucks. This involves an elaborate distribution system to supply the required cylinders of compressed gas, but it might be a market outlet for waste refinery gas, natural gas, butane, etc. This has also been tried abroad.

In England experiments on motorbusses have indicated that a self-contained system of gas generated from charcoal can be used with

[24] United States Bureau of Mines. See footnote 22, p. 100.
[25] United States Bureau of Mines. See footnote 22, p. 100.
[26] United States Bureau of Foreign and Domestic Commerce. World trade notes, miscellaneous statistics. 1936-37. [Mimeographed.]

limited success, at least in restricted fields of automotive transportation, such as busses and motor lorries. As a further adaptation of the idea, the generation and compression of coal gas at a central plant is being tried in both England and Germany (*69*). This avoids the necessity for a compression and generating system on the vehicles themselves. In experiments at Munich, Germany (*41*), wood is used as a source of gas produced in a generator attached to the automobile. Wood charcoal has been similarly used in England and involves an operating cost of only about one-tenth of the cost of petrol (*23*).

Both Italy and France have recently required public transportation lines to use fuels of domestic origin. In Italy this rule became effective on January 1, 1938. It is estimated that about 240 busses were equipped to use wood or charcoal, and about 30 were operated on a mixture of benzol and methanol (*3*). The regulation in France becomes effective in 1939.

A further use of charcoal may come with the perfection of a rotary engine designed to be operated by charcoal-dust explosions within the engine itself. Other combustible material, such as starch, might be substituted.

Russia is using heavy oils from peat as fuel for oil and Diesel engines (*62*). Tung oil and other vegetable oils have been tried in China.

The present use of motor fuels may be revolutionized by the development and perfection of a light Diesel engine, operated by cheap, heavy fuel. The successful design of a light Diesel with the flexibility and other advantages of the present Otto-cycle type may change the entire present use of internal-combustion engines and present an entirely new set of problems.

Alcohol From Wood or Cellulose

It is possible to produce hexose sugars from vegetable materials by hydrolyzing cellulose or other carbohydrate constituents with dilute mineral acids. Since wood consists of approximately 60 to 80 percent of carbohydrates (40-percent alpha cellulose), it provides the most concentrated and satisfactory cellulosic raw material. In the hydrolyzing operation the pentosans, which are present in wood to the extent of 6 to perhaps 25 percent, are similarly hydrolyzed to pentose sugars such as xylose.

Experiments on the production of sugars and alcohol from vegetable fibers are recorded as far back as 1819. Early in 1900 Claassen, in Germany, developed a hydrolysis process using sulphur dioxide or sulphurous acid, which in 1903 received commercial trial in two factories in the United States—at Highland Park, Chicago, Ill., and Hattiesburg, Miss. This process was commercially unsuccessful. The Claassen Co. later erected a plant at Port Hadlock, Wash., using sulphur dioxide. This also was a failure. Ewen and Tomlison, after experimenting with steam and sulphur dioxide, turned to sulphuric acid as a hydrolyzing agent and erected a commercial plant at Georgetown, S. C., for the production of alcohol from saw mill waste. The yields from this plant averaged about 20 gallons of alcohol per ton of wood waste, with occasionally higher yields from certain woods or under particular conditions (*34*). Further experimental work was

conducted by the United States Forest Products Laboratory at Madison, Wis.[27]

Abroad, Willstätter discovered that concentrated hydrochloric acid (40-percent) dissolves cellulose and inverts the cellulose solution to sugar. On this basis the process of Hagglund and (later) Bergius was developed at Rheinau. Dangiville also, in 1880, had experimented with the action of gaseous hydrochloric acid, and this was brought to a semicommercial development by Terrisse and Lévy at Geneva, the process as improved becoming known as the Prodor process (*52*).

In recent years the Bergius process has reached the commercial stage, but one of the principal difficulties has been the recovery of the acid, as this process requires special ceramic apparatus. The diffusion battery employed in the Prodor process was an improvement, but it has been difficult to find a suitable construction material for the equipment (*52*).

In 1926 Scholler attacked the problem, using heated dilute mineral (now sulphuric) acid instead of the cold concentrated hydrochloric acid used by Bergius, because of a theory that the low yields of the Bergius process were partly due to the decomposition of the sugar before it could be removed (*52*). The Scholler process has reached the commercial stage at Tornesch, Germany. It has recently been tried at a plant in the United States, and plants in other countries have been contemplated. Greatly increased yields are claimed in Germany, but the American trial has not been commercially successful, as far as can be ascertained.

The Bergius process (*13*) requires the use of shredded dry wood, which is treated in the cold with concentrated hydrochloric acid on a counter-current principle at ordinary pressures. After considerable time in solution the sugar product is finally recovered from the acid mixture by vacuum distillation, the acid being regenerated and reconcentrated in ceramic evaporators. About 80 percent of the acid is flashed off, and the rest of the solution (containing 90 percent of sugar, 1 to 2 percent of acid, and 8 percent of water) is recovered as a solid in a cyclone separator. It is claimed that from 60 to 66 percent of the original wood is recovered as sugar, producing 85 to 90 gallons of alcohol per long ton of dry wood. The sugar must be hydrolyzed further before it can be wholly fermented. Perhaps 80 percent of the raw sugar is convertible into alcohol. Xylose and possibly other pentose sugars from the pentosans concentrate in the wash liquor and can be used as stock feed but not as a source of alcohol. Acetic acid is also produced as a byproduct, in amounts about equal to that produced in the destructive distillation of wood.

In the Scholler process (*61*) wet wood may be used, and claims have been made that shredding is not required, although some difficulty with channeling may be experienced. The wood is subjected to percolation with a 1-percent sulphuric acid solution at 170° C. and 119 pounds' pressure, the sugar being periodically removed from the acid solution to reduce decomposition losses. No recovery of the dilute acid solution is necessary. The percolators are lined with acid-proof brick. Based on a cost for wood of $3.50 a ton (an estimate

[27] SHERRARD, E. C. THE MANUFACTURE OF ETHYL ALCOHOL FROM WOOD WASTE. U. S. Forest Service, 20 pp. 1920. [Mimeographed.

which is probably too low) and an estimated yield of 54 gallons of alcohol per ton, the production cost is calculated to be 9.8 cents a gallon. About 33 percent of lignin, some furfural and acetic acid, and waste glucose suitable for stock feed are also recovered.[28]

It is significant that the published reports of the wood-conversion processes indicate a total possible recovery of various products in excess of 100 percent of the original raw material for a complete process. The lignin recovered still finds little commercial use, being largely coked in the Bergius process. It will have to have considerable value in order that the process may have any chance of economic success. The fermentable sugars have been used as a source of alcohol or yeast. Hawley (*34*) states that softwood yields a higher percentage of fermentable sugars than hardwood, the total sugar produced by any method, however, being approximately the same. The unfermentable sugars are used as a stock feed or as a source of lactic or acetic acids, although Claassen has reported unfavorably on the costs of such wood byproducts (*22*). It does not seem that the possibilities of wood for alcohol production can compare with those of many agricultural crops. Wood waste, at a nominal cost, might have a sufficiently low raw-material cost in comparison with agricultural crops. However, assuming a growth of 1 cord per acre each year, the financial return per acre would be far below that of grain, without considering byproducts, which in the case of corn are now of greater value than wood byproducts.

UTILIZATION OF FARM WASTES

Cornstalks, straws, nutshells, and similar cellulosic materials, generally referred to as farm wastes, might be substituted for wood in the above-mentioned hydrolyzation processes, as these materials have the same essential constitution as wood. A profitable use for the byproduct lignin, which may equal or exceed the amount of cellulose present, would have a favorable effect on the economic success of these processes.

Table 30 shows the estimated amounts of cellulosic crop wastes annually produced in the United States and the amount available to industry. The total waste for all the crops is estimated to be approximately 260 million tons annually. On the basis of 30 gallons of alcohol per ton, this quantity of material might produce 7,800,000,000 gallons of alcohol.

[28] UNITED STATES BUREAU OF FOREIGN AND DOMESTIC COMMERCE. Chemical Division Special Circular 369. 1932. [Mimeographed.]

TABLE 30.—*Estimated quantities of the principal cellulosic farm wastes produced in the United States each year and the probable quantities available to industry* [1]

Material	Principal sources	Total production	Probable quantity available to industry
		Tons	*Tons*
Artichoke, tops [2]			
Bagasse [3]	Florida, Hawaii, Louisiana, Puerto Rico, Philippine Islands, Virgin Islands.	3,801,425	2,740,000
Corncobs (78)	Iowa, Illinois, Indiana, Missouri, Nebraska, Ohio	17,426,000	5,275,000
Cornstalks (78)	do	104,000,000	64,166,000
Cotton, bolls and stalks [3]	Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Texas.	20,450,000	14,314,000
Hulls:			
Oat [3]	Illinois, Iowa, Minnesota, Wisconsin	5,280,000	321,475
Rice [3]	Arkansas, California, Louisiana, Texas	195,000	189,282
Seeds:			
Grape (78)	California	79,258	31,780
Raisin (78)	do	32,860	24,500
Shells:			
Almond (78)	do	3,594	
Apricot pit (78)	do	22,580	19,200
Cherry pit (78)	California, Michigan, New York, Oregon, Washington.	14,150	7,420
Peach pit [3]	California, Georgia	190,750	46,200
Peanut [3]	Alabama, Georgia, North Carolina, Texas, Virginia.	240,000	75,000
Prune pit (78)	California, Idaho, Oregon	69,305	
Straws:			
Barley [3]	Iowa, Minnesota, Nebraska, North Dakota, South Dakota, Wisconsin.	6,901,000	5,176,000
Flaxseed [3]	Minnesota, Montana, North Dakota, South Dakota.	1,671,000	1,367,000
Oat [3]	Illinois, Iowa, Minnesota, Wisconsin	22,883,000	1,149,000
Peanut [3]	Alabama, Georgia, North Carolina, Texas, Virginia.	941,412	
Rice [3]	Arkansas, California, Louisiana, Texas	1,169,000	877,000
Rye [3]	Minnesota, North Dakota, South Dakota	2,797,300	2,098,300
Wheat [3]	Kansas, Minnesota, North Dakota, South Dakota	49,954,000	37,465,000

[1] Computed largely by T. R. McElhinney, Industrial Farm Products Research Division, Bureau of Chemistry and Soils.

[2] Practically none produced commercially.

[3] United States Department of Agriculture preliminary estimates of farm products, byproducts, and wastes available for industrial use. 34 pp. 1935. [Mimeographed.]

WASTE SULPHITE LIQUORS FROM PAPER-PULP MILLS

The liquor obtained as a waste product in the pulping of wood by the sulphite process contains from 2 to 3.5 percent of sugars, about 65 percent of which is fermentable to alcohol. Before such a liquor can be fermented, the sulphur dioxide, as well as the acetic and formic acids contained in it, must be neutralized, usually with lime or calcium carbonate. A special type of yeast which has been acclimated to sulphite liquors is generally used as the fermenting agent. The fermentation requires from 60 to 90 hours and yields a quantity of alcohol equivalent on the average to 1 percent of the volume of liquor fermented. The difficulty is the cost of evaporation, as there are about 2,100 pounds of solids in 2,000 gallons of waste water per ton of pulp.

The sulphite pulp-cooking method is somewhat analagous to the Scholler dilute-acid wood-conversion process, except that the former effects only minor decomposition of cellulose. It is estimated that the waste liquor from 1,000 kg of cellulose (representing 8 to 10 times the weight of the cellulose) contains 644 kg of lignin and 311 kg of carbohydrates, together with 425 kg of lignosulphonic acid, calcium salts, proteins, resins, etc. The carbohydrates are mostly sugars and

occur somewhat as follows (*31*): Pentosans, nonfermentable (arabinose), 26.9 percent; mannose, 15.6; galactose, 8.1; glucose, 49.4 percent. Yields of 15 gallons of 95-percent alcohol per ton of sulphite pulp have been reported. It is also possible to recover sulphur dioxide and residual organic fuel (*12*).

The process utilizing this material has never been employed to any great extent in the United States, although recently one plant has been fermenting paper-mill liquor in combination with molasses. It is an important source of industrial alcohol in the Scandinavian countries and in Germany. It is estimated that 18 plants in Sweden were using this process in 1930 (*12*). About 25,351,000 liters of ethyl alcohol (100-percent) were produced from sulphite liquor in Sweden in 1936. About 16 million liters of this were used for motor-fuel blends.

If the processing of cellulosic farm wastes for paper becomes successful, the waste liquors therefrom might be suitable for alcohol recovery, in the same manner as sulphite liquor from wood pulp.

USE OF BLENDED MOTOR FUELS ABROAD [29]

The practice in many foreign countries of enforcing by legislation the blending of alcohol from agricultural sources with gasoline, benzol, or similar substances for motor-fuel purposes has led to the advocacy of a similar procedure in the United States as an agricultural-relief measure. Such advocacy frequently fails to consider the essential differences between conditions in foreign countries and in the United States. It is true that certain foreign countries have attempted to accomplish certain agricultural adjustments by the use of alcohol motor fuel, but behind this fact there are usually other contributory causes, such as a lack of adequate fuel resources, so that compulsory use of alcohol motor fuels becomes only part of a program of national self-sufficiency of raw materials. The factors of national defense, international-trade balances, internal economic adjustments, oil shortages, etc., have a marked bearing on the situation, which is not identical in any two countries.

Because of the high price of motor fuels and the frequently high taxation rate on automobiles, there is a tendency to design foreign automobile engines and cars with tax economy in mind. The development of small cars with engines of high speed, small cylinder bore, and high compression ratios has resulted. Such engines can use, and in fact require, special fuels and are frequently of the type that can use alcohol fuels to better advantage than do the engines of American cars.

According to a survey made by the United States Department of Commerce (*46*), approximately 50 countries or territories had considered some form of alcohol motor fuel by 1932, but not all of them had made their use compulsory. Owing to political disturbances in foreign countries in the past few years, important changes have taken place in the motor-fuel situation. The following paragraphs discuss these changes, particularly in countries where the use of alcohol fuels has been compulsory.

[29] Unless specific references are mentioned, the material in this section was obtained from various news reports.

GERMANY

Germany was perhaps the first nation to resort to the use of alcohol as a fuel. This use of alcohol was originally intended to benefit agriculture by stimulating the growing and industrial utilization of potatoes, and also, to dispose of a large post-war surplus of alcohol. Many small alcohol distilleries are located on farms or estates. On January 1, 1936, Germany introduced the use of methanol for motor-fuel blends, and subsequently (Oct. 1, 1937) reduced the amount of ethyl alcohol and increased the amount of methanol in nonbenzol blends. The country has built up facilities for the production of synthetic methanol on a large scale, and presumably a surplus now exists. Present trends are toward reduced use of agricultural alcohol and the substitution of increasing amounts of methanol or other substances.

Germany, which is lacking in petroleum deposits but has large quantities of coal, is now engaged in a vast research program for the production of synthetic fuel, principally from coal. Germany's estimated capacity for production of synthetic fuel is shown in table 31. An attempt is being made to achieve self-sufficiency in all phases of national need, under a national plan, and the manufacture and sale of all commodities are strictly regulated by decree.

TABLE 31.—*Production of motor fuels in Germany in 1935 and estimated plant capacity in 1937*

Motor fuel	Production in 1935	Estimated plant capacity by the end of 1937
Light:	*Metric tons* [1]	*Metric tons* [1]
Synthetic gasoline from lignite	230,000	900,000
Synthetic gasoline from anthracite		250,000
Benzol from gas works	400,000	410,000
Alcohols (methyl and ethyl)	180,000	250,000
Liquid gases (propane, etc.)		45,000
German petroleum	120,000	150,000
Total	930,000	2,005,000
Heavy	158,000	290,000

[1] About 300 U. S. gallons of petroleum to a metric ton.

If the proposed plants were constructed and were being operated, the production of synthetic gasoline in 1937, in metric tons, was expected to be as follows: From lignite, I. G. Farbenindustrie hydrogenation process, 350,000; Lurgei hydrogenation of coal tar, 400,000; Fischer-Tropsch synthesis, 150,000; from anthracite, Fischer-Tropsch synthesis, 100,000; I. G. Farbenindustrie hydrogenation process, 150,000.

Insofar as available information can be interpreted, the original idea of using alcohol motor fuels produced from agricultural products has practically vanished as a result of the new politico-economic situation. German motor fuels are changing in constitution every day, but through it all a new fuel is emerging. At present this consists of a mixture of benzol, synthetic fuel, alcohols, hydrogenation products, and petroleum. This mixture varies with the supply of the several constituents available, but eventually it may be standardized. The German name for motor fuel is benzine, but it is not gasoline; it

may be made from anything available. The octane rating of the mixed fuels is comparatively high.

FRANCE

In France the alcohol industry is practically a Government monopoly, maintained as a defense measure. The raw material is principally sugar beets. The alcohol in excess of normal peacetime trade requirements is used as motor fuel, any extra expense incurred from lower alcohol prices falling ultimately on the national treasury. The variation in the supply of alcohol available for use as motor fuel causes motorists difficulties arising from variable and nonstandard blends.

France is the fourth-largest consumer of crude petroleum oil, and the 6 million tons it uses annually must come almost wholly from outside. Increase in army mechanization may raise the requirements to 8 million tons annually. The denaturing methanol used is required by law to be produced in France.

ITALY

In the past, Italy produced an excess of alcohol over normal needs. Alcohol motor-fuel legislation, initiated in 1926, received impetus in 1929 because of a simultaneous overabundance of molasses and a heavy carry-over of low-grade wine unfit for use as a beverage. The use of a 20-percent blend of ethyl alcohol was authorized to begin January 1936, but enforcement is dependent on the supply of alcohol available. Certain types of motors are exempt from this law. A decree of November 7, 1935 (No. 1965) provided that all alcohol produced from sugar beets in the 1935–36 season be held at the disposal of gasoline manufacturers and that no alcohol be withdrawn for other use until the entire amount required for motor-fuel blending had been accumulated. Such alcohol had to be anhydrous and denatured. Producers of alcohol from other sources must also set aside their quota. Changes in motor-fuel regulations occur frequently, but complete enforcement varies with the crop and the national requirement. A decree passed in 1938 required the addition of alcohol to imported gasoline.

Because of the fundamental need of fuel for defense purposes, beets, molasses, grapes, corn, potatoes, rice, cellulose, etc. are now being used for alcohol production.

In 1938 the use of methanol and of charcoal-gas generators was made obligatory in certain sections. The production of methanol may soon reach 25,000 tons a year. (Because of defense-of-the-realm regulations, specific information is difficult to obtain.)

Italy has some petroleum and employs cracking units at several refining plants, but produces no natural or polymerized gasoline. Cracking plants operate partly on imported petroleum residuum. Asphaltic rock is used as a fuel source at Rome, and special bounties are given for fuels produced from lignite and by hydrogenation.

The octane ratings of fuels range from 60 to 70. Only a limited amount of tetraethyl lead is used, the alcohol serving instead.

The entire complicated motor-fuel program is prompted by economic nationalism, and bears some resemblance to the situation in Germany.

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The average cost of motor fuel is probably higher than in any other country.

Estimates of replacement fuel used in Italy in 1937 have been assembled in table 32.

TABLE 32.—*Substitute motor fuels used in Italy in 1937 and their equivalent in gasoline*

Fuel	Quantity	Gasoline equivalent
	Tons	*Tons*
Wood charcoal	23,000	16,500
Olive-pit charcoal	3,000	2,300
Ethyl alcohol	10,000	6,500
Methanol	1,200	700
Benzol	2,500	2,400
Methane	1,300	1,600
Total	41,000	30,000

AUSTRIA

Since 1934 the addition of alcohol to gasoline for motor fuel has been compulsory in Austria. The amount specified was 20 to 40 percent, depending on the supply available. When first promulgated, in 1931, the decree was operative only when the price of gasoline was greater than the price of alcohol. This decree was abolished in 1933. Blended fuels were produced in Austria, and no straight alcohol was used as fuel. The use of alcohol in motor fuels was promoted by the Austrian Government for farm relief rather than because of economic nationalism. The merging of Austria with Germany will no doubt affect the status outlined above.

ENGLAND AND IRELAND

In 1934 Government factories in the Irish Free State were authorized to produce motor-fuel alcohol from potatoes. This alcohol is exempt from tax if used in motor-fuel (10-percent) blends.

In England alcohol blends can be sold at the same market price as first-rate gasoline. The methylated spirits regulation of 1930 ruled that alcohol used in internal-combustion engines should be tax-free, provided that it was blended with a minimum of 25 percent of gasoline or benzol, whereas straight gasoline paid a tax of 8 pence per gallon. In addition, under the Revenue Act of 1906, motor-fuel alcohol received a Government allowance of 5 pence per proof gallon, or 8¾ pence per imperial gallon. In May 1938 the tax on gasoline was increased to 9 pence, and this also became effective on alcohol blends. There is no petroleum in England, but the British nation is understood to be heavily interested in Burma and other oil fields.

SPAIN

In Spain a decree making the use of alcohol in motor fuel compulsory was issued in 1935. Because of the civil war, information on the present situation is not obtainable.

SWEDEN

In Sweden ethyl alcohol is produced principally from sulphite pulp, about 16 million liters from this source having been used in motor fuels in 1936. Blends are known as Lättbentyl. Some alcohol is produced from potatoes. Alcohol in fuel for Government-owned vehicles has been compulsory since 1934. About 450 wood and charcoal gas generators were used on automobiles in 1935, though this number has since decreased. The Government is pushing the production of shale oil.

SWITZERLAND

In 1936 the Swiss Government decreed that the use of alcohol in motor fuels should be compulsory as soon as the necessary supply was available.

CZECHOSLOVAKIA

In Czechoslovakia the compulsory addition of methyl alcohol to motor fuel has been recently increased from 2 to 2.5 percent (*35*). The law passed in 1932 requires 20 percent of mixed alcohols in the gasoline. A gasoline-alcohol-benzol blend which has a higher alcohol content is used on railways. This is known as Dynakol. The alcohol is produced in cooperative agricultural distilleries, since a surplus of agricultural materials exists.

OTHER EUROPEAN COUNTRIES

Bulgaria attempted to pass an alcohol-fuel law in 1934, and in 1936 Lithuania passed legislation requiring a 25-percent blend. Hungary requires a 20-percent mixture called Motalco. Latvia has changed the 25-percent mixture originally required to 50 percent in summer and 33⅓ percent in winter. Jugoslavia's 20-percent blend, originally compulsory, has been voluntary since 1933. In Poland the Government alcohol monopoly has an agreement with the petroleum companies by which the petroleum company purchases anhydrous alcohol equivalent to 9 percent of the gasoline consumed. This arrangement effects the sale and use of alcohol in blends without mandatory legislation. About 50 percent of the domestic motor fuel is blended with alcohol (22 to 30 percent), but the remainder is sold as straight gasoline. In all these countries alcohol motor fuel is used largely as an aid to agriculture.

AUSTRALIA

In Australia the use of alcohol as motor fuel is confined to Queensland, where all distributors of gasoline are required by law to purchase a quantity of pure alcohol equal to 1.5 percent of the volume of gasoline they bring into the State. There is no law or regulation, even in Queensland, that requires the use of alcohol as a constituent part of the gasoline sold, but of course the gasoline companies, in order to dispose of the alcohol they are forced to purchase, use it for blending with certain grades of gasoline. It has been reported that there is an organized effort to have the Government compel the gasoline companies to use alcohol to the extent of 15 percent of the volume of imported gasoline.

The problem in Australia appears to be lack of petroleum and the utilization of farm byproducts such as wheat and sugarcane blackstrap molasses.

JAPAN

Japan has a 7-year program for attaining self-sufficiency with respect to motor fuels. Coal is plentiful, but petroleum reserves are lacking. An alcohol monopoly was created in 1937. Alcohol used for motor fuel in Japan at present is unimportant, except perhaps for military purposes. A compulsory alcohol motor-fuel law was passed in 1937, but is not yet in effect as the small amount of alcohol produced, mainly from Formosa cane molasses, is needed for chemical manufacture. Potatoes and sweetpotatoes are being considered as raw materials for alcohol. Production of motor fuel by coal hydrogenation is being experimented with, and a program of hydrogenation plant construction has been initiated. Japan is committed to a general program of self-sufficiency, and in view of recent events, a rapid change in the present economic situation may be anticipated.

PHILIPPINE ISLANDS

In the Philippine Islands there has been an excess of molasses since the enforcement of the sugar-quota law in the United States. Alcohol made from this molasses is used in fuel blends, although there is no specific law requiring it. However, such a law has been proposed.

CUBA

Motor-fuel blends are used in Cuba, but are not required by law. Sponsors of the use of alcohol in motor fuel feel that extensive use of such mixtures would benefit both the molasses producers and the farmers growing sugarcane, and indirectly would benefit farm laborers. Large supplies of petroleum are available.

CHILE

A law making the use of 10 to 15 percent of alcohol in motor fuels compulsory was passed in Chile in 1931. There has been a shortage of alcohol, however, and recent blends are as low as 6 percent. Here again the problem of excess cane molasses is probably the reason for the law. Chile has no petroleum.

PANAMA

In Panama an executive decree in 1933, effective in 1934, authorized the marketing of a gasoline-alcohol blend called alcoholina, but use of the blend is not compulsory. The move was intended to benefit sugarcane growers. A subsidy was provided, but the cost of the alcohol was too great, and efforts to encourage its use in motor fuels have largely ceased.

PERU

In Peru, as a protection to the sugar industry, the use of alcohol blends is allowed on farms only in quantities not to exceed their own requirements. There are no other regulations. The Government receives an income from gasoline importations.

BRAZIL

No petroleum is produced in Brazil. In 1934 the Government authorized the sale of 10-percent alcohol blends, which was raised to 15 percent for Rio de Janeiro in 1937. The alcohol supply has been

insufficient, although in the past 2 years the efforts of the Alcohol Institute have increased alcohol production. The requirement is an outgrowth of the farm-relief sugarcane problem.

ANGOLA AND MOZAMBIQUE

Since 1933 two blends—one containing 25 percent of alcohol and one containing 75 percent—have been compulsory in Angola. In Mozambique a 25-percent blend was decreed in 1932 but, because of the lack of dehydrated alcohol, has not been enforced.

UNION OF SOUTH AFRICA

The "new Union motor spirit," composed of approximately 40 percent of anhydrous alcohol and 60 percent of gasoline and ether, is manufactured and marketed in Natal Province. There is no law requiring its use. National defense plans make it desirable for the Government to foster this industry because of the lack of oil resources.

ALCOHOL MOTOR FUEL EXPERIMENTS IN THE UNITED STATES

In the United States the idea of using alcohol from farm crops as a motor fuel is not new. In 1907 the Department of Agriculture published bulletins (*44*, *45*) relating to the possible use of alcohol in internal-combustion engines as then designed, and the Iowa Agricultural Experiment Station also did some work along this line (*26*). In 1909 the Geological Survey published on the same subject (*64*). The Bureau of Mines reported on it in 1911 and 1912 (*64*, *65*). The Department of Agriculture also experimented with a small distillery for the production of industrial alcohol from farm crops (1910).

Little progress toward use of alcohol fuel was made, however, until the low-crop years of 1931–32, when because of the large surplus of unsalable grains and the low income on farms, the idea of using alcohol from farm crops as a motor fuel was again advanced.

In 1933 road tests of alcohol fuels were made by the National Bureau of Standards in cooperation with automotive groups.[30] Similar road tests were made at the Iowa State College,[31] where a series of studies was made on various aspects of the problem because of the surplus corn in Iowa.[32] The Chemical Foundation became interested in alcohol motor fuel about 1935, and this resulted in the establishment of a trial production plant at Atchison, Kans. Recently the operations of this plant, particularly in the merchandizing of alcohol motor fuels, have created widespread interest in the Middlewest, which has resulted in proposals to erect similar plants at other points in the Mississippi Valley. The State of Idaho is erecting a pilot plant at Idaho Falls for study of alcohol production from cull potatoes. In the past few years the large amount of data published on the subject has resulted in partially clarifying controversial points. Legislation designed to advance the use of alcohol motor fuels has been introduced in various State legislatures and in Congress, but thus far has failed of

[30] UNITED STATES NATIONAL BUREAU OF STANDARDS. SUMMARY OF BUREAU OF STANDARDS ALCOHOL-GASOLINE BLEND ROAD TESTS (MADE MAY 8-24, 1933.) 1933. [Mimeographed.]

[31] MOYER, R. A., and PAUSTIAN, R. G. ROAD TESTS ON ALCOHOL-GASOLINE MIXTURES. Iowa State Col. Agr. Prog. Rept. 7. 1933. [Mimeographed.]

[32] IOWA STATE COLLEGE. USE OF ALCOHOL IN MOTOR FUELS. Iowa State Col. Agr. Prog. Repts. 1 to 7. 1932–33. [Mimeographed.]

passage except in the State of Nebraska, where the State gasoline tax is remitted on the alcohol portion of a blended fuel.

GASOLINE CONSUMPTION ON THE FARM

Although the production of motor-fuel alcohol from agricultural products has been advanced as a panacea for farm financial troubles, it must be borne in mind that the farmer will pay a large part of any increased motor-fuel bill. The following tabulation, which lists the estimated percentage of farm-owned vehicles in each State in 1935, indicates that in the Middle Western States generally from 30 to 50 percent of all the automobiles and trucks registered in the State are on the farms. These are the States that would largely supply the raw materials for alcohol production. Coastal and industrial States, or States in which an unusually large percentage of the population is in the cities, would be less likely to favor the use of alcohol in motor fuel under present conditions.

Farm-owned vehicles in 1935

	Percent		Percent
North Dakota	49. 8	Utah	22. 6
South Dakota	44. 7	Colorado	21. 2
Mississippi	43. 3	Indiana	20. 7
Nebraska	39. 4	Maine	20. 2
Montana	38. 5	Delaware	20. 1
Kansas	34. 5	West Virginia	19. 8
Arkansas	34. 3	Louisiana	19. 4
Idaho	34. 1	Washington	17. 8
Iowa	34. 0	New Hampshire	16. 0
Wisconsin	32. 1	Maryland	15. 6
New Mexico	31. 6	Michigan	15. 5
Minnesota	30. 8	Ohio	15. 0
South Carolina	30. 4	Arizona	14. 5
Alabama	30. 2	Illinois	14. 1
Vermont	29. 8	Pennsylvania	12. 5
Virginia	29. 2	Florida	12. 2
Kentucky	28. 7	Nevada	12. 0
North Carolina	28. 0	Connecticut	9. 1
Wyoming	27. 9	New York	9. 1
Oklahoma	27. 0	California	8. 8
Georgia	26. 4	Rhode Island	5. 1
Tennessee	25. 8	New Jersey	4. 5
Missouri	25. 3	Massachusetts	4. 2
Texas	24. 5	District of Columbia	. 1
Oregon	23. 6		

Estimates of the farm population by States and the motor vehicles (passenger cars and trucks) on farms for each State are given in tables 33 and 34. Estimates of motor vehicles on farms in 1935 have been calculated on the basis of the 1930 census figures and the total State registrations of vehicles for 1935, the difference in farm population between 1930 and 1935 being interpolated. Data from other sources seem to indicate that these figures are probably lower than the actual number on the farm.

TABLE 33.—*Farm population in 1930 and 1935 (79)*

State	1930 census			1935 census		
	Total in State	Total on farm	Percent on farm	Total in State	Total on farm	Percent on farm
Alabama	2, 646, 248	1, 340, 277	50. 6	2, 834, 000	1, 386, 074	48. 9
Arizona	435, 573	98, 995	22. 7	386, 000	100, 083	25. 9
Arkansas	1, 854, 482	1, 119, 464	60. 4	1, 999, 000	1, 180, 238	59. 0
California	5, 677, 251	620, 506	10. 9	5, 639, 000	608, 838	10. 8
Colorado	1, 035, 791	282, 827	27. 3	1, 062, 000	276, 198	26. 0
Connecticut	1, 606, 903	86, 770	5. 4	1, 717, 000	143, 157	8. 3
Delaware	238, 330	46, 530	19. 5	256, 000	48, 558	19. 0
Florida	1, 468, 211	278, 981	19. 0	1, 614, 000	319, 658	19. 8
Georgia	2, 908, 506	1, 418, 514	48. 8	3, 345, 000	1, 405, 944	42. 0
Idaho	445, 032	188, 365	42. 3	479, 000	198, 983	41. 6
Illinois	7, 630, 654	999, 249	13. 1	7, 817, 000	1, 017, 650	13. 0
Indiana	3, 238, 503	813, 007	25. 1	3, 429, 000	852, 994	24. 8
Iowa	2, 470, 939	977, 906	39. 6	2, 534, 000	967, 979	38. 2
Kansas	1, 880, 999	707, 196	37. 6	1, 848, 000	703, 743	38. 1
Kentucky	2, 614, 589	1, 176, 524	45. 0	2, 846, 000	1, 307, 816	45. 8
Louisiana	2, 101, 593	830, 606	39. 5	2, 120, 000	859, 351	40. 4
Maine	797, 423	170, 995	21. 4	845, 000	184, 697	21. 9
Maryland	1, 631, 526	237, 456	14. 6	1, 669, 000	241, 596	14. 5
Massachusetts	4, 249, 614	123, 255	2. 9	4, 375, 000	163, 210	3. 7
Michigan	4, 842, 325	782, 394	16. 2	4, 661, 000	840, 514	18. 0
Minnesota	2, 563, 953	895, 349	34. 9	2, 627, 000	928, 487	35. 3
Mississippi	2, 009, 821	1, 362, 843	67. 8	1, 961, 000	1, 332, 981	67. 8
Missouri	3, 629, 367	1, 114, 484	30. 7	3, 913, 000	1, 183, 499	30. 2
Montana	537, 606	204, 594	38. 1	531, 000	195, 262	36. 7
Nebraska	1, 377, 963	585, 701	42. 5	1, 364, 000	580, 694	42. 6
Nevada	91, 058	16, 441	18. 1	99, 000	15, 385	15. 6
New Hampshire	465, 293	62, 850	13. 5	502, 000	76, 007	15. 1
New Jersey	4, 041, 334	131, 096	3. 2	4, 288, 000	144, 368	3. 4
New Mexico	423, 317	158, 631	37. 5	402, 000	189, 358	47. 0
New York	12, 588, 066	719, 929	5. 7	12, 889, 000	784, 483	6. 1
North Carolina	3, 170, 276	1, 599, 918	50. 5	3, 417, 000	1, 623, 481	42. 4
North Dakota	680, 845	397, 294	58. 4	700, 000	385, 614	55. 1
Ohio	6, 646, 697	1, 013, 229	15. 2	6, 707, 000	1, 121, 405	16. 8
Oklahoma	2, 396, 040	1, 024, 070	42. 7	2, 509, 000	1, 015, 562	40. 5
Oregon	953, 786	223, 667	23. 5	1, 008, 000	248, 767	24. 8
Pennsylvania	9, 631, 350	856, 694	8. 9	10, 066, 000	975, 082	9. 7
Rhode Island	687, 497	16, 477	2. 4	681, 000	21, 751	3. 8
South Carolina	1, 738, 765	916, 471	46. 5	2, 012, 000	1, 308, 420	45. 1
South Dakota	692, 849	390, 205	56. 3	675, 000	358, 204	53. 0
Tennessee	2, 616, 556	1, 215, 452	46. 5	2, 904, 000	1, 308, 420	45. 1
Texas	5, 824, 715	2, 352, 272	40. 4	6, 077, 000	2, 332, 693	38. 2
Utah	507, 847	115, 713	22. 8	515, 000	138, 242	26. 8
Vermont	359, 611	112, 904	31. 4	377, 000	122, 655	32. 6
Virginia	2, 421, 851	950, 757	39. 3	2, 637, 000	1, 053, 469	39. 9
Washington	1, 563, 396	304, 737	19. 5	1, 633, 000	335, 840	20. 6
West Virginia	1, 729, 205	449, 114	26. 0	1, 816, 000	561, 919	30. 8
Wisconsin	2, 939, 006	881, 054	30. 0	2, 908, 000	930, 515	32. 0
Wyoming	225, 565	73, 152	32. 4	232. 000	74, 507	32. 0
District of Columbia	486, 869	435	. 1	594, 000	532	. 1
Total	122, 774, 996	30, 445, 350	24. 8	127, 519, 000	32, 154, 883	25. 2

TABLE 34.—*Motor vehicles on farms in 1930 and 1935*

State	1930 census (79)				1935 [1]			
	Passenger cars		Motortrucks		Passenger cars		Motortrucks	
	Number	Percent of total in State	Number	Percent of total in State	Number	Percent of total in State	Number	Percent of total in State
Alabama	73,634	30.8	12,838	33.9	60,500	29.7	12,750	32.7
Arizona	9,916	10.1	3,062	25.5	9,800	11.5	5,240	29.1
Arkansas	65,935	34.1	11,000	40.7	55,600	33.3	15,940	39.8
California	136,842	7.6	40,971	17.8	144,000	7.6	44,750	17.6
Colorado	52,258	18.9	16,918	53.3	46,100	18.0	14,400	50.7
Connecticut	13,154	4.7	6,344	12.4	22,500	7.2	11,820	19.0
Delaware	8,724	19.1	2,996	28.5	8,730	18.6	2,690	27.8
Florida	26,387	9.6	12,203	22.9	29,905	10.0	13,620	23.8
Georgia	88,479	30.0	15,967	33.9	84,510	25.8	19,420	29.2
Idaho	33,966	32.7	6,281	43.2	31,200	32.2	9,100	42.5
Illinois	192,873	13.5	40,371	19.4	180,000	13.4	35,640	19.2
Indiana	154,556	20.6	30,037	23.4	145,890	20.3	30,800	23.1
Iowa	240,512	34.0	32,669	45.3	202,200	32.8	35,200	43.6
Kansas	171,018	33.4	33,648	40.4	158,000	33.8	33,400	41.8
Kentucky	86,784	29.4	7,188	20.1	91,000	29.9	8,925	20.5
Louisiana	43,082	18.6	9,281	20.7	39,700	19.0	12,500	21.1
Maine	26,227	17.6	10,781	28.8	25,750	18.0	11,200	29.4
Maryland	37,972	13.4	11,284	30.0	39,500	13.3	14,450	29.8
Massachusetts	17,638	2.4	9,572	9.3	21,200	3.1	11,825	11.8
Michigan	150,922	13.0	36,768	22.0	160,850	14.5	31,200	24.5
Minnesota	185,717	29.8	36,557	33.8	187,500	30.2	36,225	34.2
Mississippi	85,563	42.2	16,503	49.2	64,500	42.2	16,400	49.2
Missouri	176,466	26.4	20,132	22.0	168,950	26.0	25,025	21.6
Montana	38,166	34.8	14,615	57.0	38,200	33.5	19,500	55.0
Nebraska	141,144	38.3	26,045	44.3	133,400	38.4	26,300	44.4
Nevada	2,921	12.5	1,241	19.8	3,020	10.8	1,170	17.1
New Hampshire	11,079	11.9	4,539	23.9	12,475	13.3	6,280	26.8
New Jersey	22,371	3.1	14,753	11.1	25,200	3.3	14,750	11.8
New Mexico	15,395	21.9	5,328	38.9	20,300	27.4	8,855	48.7
New York	141,916	7.2	58,974	17.3	155,350	7.7	56,925	18.5
North Carolina	132,876	33.5	18,558	33.1	112,000	28.1	16,100	27.8
North Dakota	78,798	50.8	16,990	61.6	65,000	48.0	16,725	58.2
Ohio	201,552	13.0	39,210	19.2	220,050	14.4	37,200	21.2
Oklahoma	127,448	25.9	23,930	40.2	103,950	24.8	31,650	38.2
Oregon	47,440	18.8	9,741	43.4	49,675	19.8	19,550	45.8
Pennsylvania	152,222	9.9	47,062	21.5	164,450	10.8	53,600	23.4
Rhode Island	2,569	2.2	1,701	8.7	4,550	3.5	2,525	13.7
South Carolina	61,754	32.1	6,966	26.5	64,050	31.1	7,650	25.7
South Dakota	81,923	45.5	14,816	59.2	65,100	42.8	14,975	55.7
Tennessee	89,022	27.0	9,039	23.9	81,200	26.2	9,805	23.2
Texas	300,176	25.9	52,580	25.4	276,500	24.5	61,700	24.0
Utah	17,574	18.3	4,189	23.4	19,050	21.5	4,845	27.5
Vermont	18,620	23.7	5,035	61.0	18,400	25.4	5,910	65.5
Virginia	88,463	27.8	19,459	34.1	91,975	28.2	20,825	34.6
Washington	55,995	14.6	18,836	29.7	59,450	15.4	21,600	31.4
West Virginia	36,978	16.4	7,432	18.4	41,400	19.5	6,400	21.8
Wisconsin	176,764	26.1	51,786	49.3	174,100	27.9	68,200	52.5
Wyoming	12,824	24.8	4,108	41.5	13,550	24.5	5,980	41.0
District of Columbia	60	.04	81	.5	65	.04	88	.5
Total	4,134,675	17.9	900,385	25.8	3,990,345	17.7	991,628	25.0

[1] Estimated from the total registration of cars and trucks, using the percentage of population on the farm (table 33) as basis.

Tentative estimates of gasoline consumption on farms are given in table 35 (use in tractors and other power devices is not included). Because of the impossibility of securing exact figures, estimated gasoline consumption on farms is based on the assumption that all automobiles use the same average amount of gasoline per year.

TABLE 35.—*Gasoline used on farms in 1930 and 1935*

State	State tax rate per gallon [1]	Gasoline consumption					
		1930			1935		
		Total used in State	Used on farms [2]		Total used in State	Used on farms [2]	
	Cents	*1,000 gallons*	*1,000 gallons*	*Percent* [3]	*1,000 gallons*	*1,000 gallons*	*Percent* [3]
Alabama	6	172,537	53,800	31.2	172,474	52,000	30.2
Arizona	5	66,750	7,850	11.7	78,359	12,050	14.5
Arkansas	6.5	128,545	44,850	34.9	131,784	41,250	34.3
California	3	1,162,338	101,300	8.7	1,464,458	128,500	8.8
Colorado	4	153,621	34,400	22.4	174,796	37,100	21.2
Connecticut	3	223,297	13,150	5.9	269,909	24,500	9.1
Delaware	4	33,779	7,050	20.8	45,085	9,100	20.1
Florida	7	227,037	26,700	11.8	256,609	31,400	12.2
Georgia	6	223,185	68,000	30.4	264,617	69,500	26.4
Idaho	5	54,423	18,400	33.8	70,310	23,950	34.1
Illinois	3	915,747	130,100	14.2	1,069,242	151,000	14.1
Indiana	4	428,969	90,500	21.1	504,867	104,400	20.7
Iowa	3	352,802	124,000	35.1	421,765	143,000	34.0
Kansas	3	304,016	104,950	34.5	295,308	102,000	34.5
Kentucky	5	168,295	47,650	28.4	201,324	57,700	28.7
Louisiana	7	184,782	35,200	19.0	186,201	36,100	19.4
Maine	4	102,737	20,500	19.9	119,821	24,300	20.2
Maryland	4	174,780	26,700	15.3	217,665	33,990	15.6
Massachusetts	3	528,147	17,000	3.2	608,021	25,600	4.2
Michigan	3	722,463	102,500	14.1	809,472	125,100	15.5
Minnesota	3	345,304	104,500	30.3	429,486	132,100	30.8
Mississippi	6	135,824	58,400	42.9	140,808	61,050	43.3
Missouri	2	431,958	111,500	25.8	512,654	129,950	25.3
Montana	5	58,838	23,000	39.1	95,739	36,800	38.5
Nebraska	5	226,511	88,500	39.2	222,584	88,600	39.4
Nevada	4	16,875	2,375	14.0	26,209	3,155	12.0
New Hampshire	4	62,487	8,700	13.9	73,903	11,810	16.0
New Jersey	3	546,685	23,750	4.4	621,031	27,900	4.5
New Mexico	5	54,386	13,350	24.6	62,881	19,850	31.6
New York	3	1,438,583	125,000	8.7	1,537,475	140,000	9.1
North Carolina	6	250,669	83,500	33.3	312,012	87,200	28.0
North Dakota	3	65,643	34,400	52.3	112,446	55,600	49.8
Ohio	4	927,036	127,000	13.7	1,014,925	152,500	15.0
Oklahoma	4	302,310	83,000	27.4	314,558	84,900	27.0
Oregon	5	154,986	32,375	20.9	183,005	43,050	23.6
Pennsylvania	4	928,843	105,450	11.4	1,171,439	146,000	12.5
Rhode Island	2	86,613	2,720	3.1	114,754	5,840	5.1
South Carolina	6	119,072	37,600	31.5	143,014	43,500	30.4
South Dakota	4	87,597	41,300	47.2	112,634	50,300	44.7
Tennessee	7	214,384	57,150	26.6	216,395	56,000	25.8
Texas	4	738,177	190,500	25.8	934,453	228,000	24.5
Utah	4	60,138	11,500	19.1	69,396	15,700	22.6
Vermont	4	46,998	12,850	27.4	51,388	15,300	29.8
Virginia	5	215,501	61,600	28.7	288,036	84,000	29.2
Washington	5	241,775	40,400	16.8	274,691	49,000	17.8
West Virginia	4	133,966	22,350	16.7	159,120	31,500	19.8
Wisconsin	4	415,742	122,000	29.2	442,436	142,000	32.1
Wyoming	4	36,175	9,880	27.3	48,241	13,400	27.9
District of Columbia	2	79,984	80	.1	112,539	113	.1
Total	[4] 3.85	14,751,310	2,709,330	18.4	17,160,339	3,187,658	18.6

[1] Dec. 31, 1936.
[2] Estimated. Based on total motor-vehicle registration and gasoline-consumption statistics, Bureau of Public Roads, and estimates of Bureau of the Census as to number of vehicles on farms.
[3] Estimated.
[4] Weighted average rate.

ALCOHOL PLANTS ON THE FARM

Suggestions have been made that the United States follow the example of Germany in developing an alcohol industry on the farm, consisting of very small plants, privately owned and operated, and adapted for utilizing local raw materials. The alcohol produced would be used locally. The industrial-alcohol law of 1906, as originally drawn, provided specifically for such a program.

The weight of reason is against such a plan. Securing alcohol in profitable quantities from any raw material requires skillful operation, careful fermentation control, and good equipment. Profit on alcohol is so small that only large-scale production is financially practicable. No small plant of adequate but simplified design, as compared with the ordinary commercial plant, has been evolved anywhere, to the knowledge of the authors. Under this system difficulties as to safeguarding against alcohol diversion would be extreme. One great difficulty would be the economic generation of steam in the required quantities, and there would be considerable fire hazard. Use of labor would be very inefficient.

Creation of a series of small rural fermentation "crude" plants, close to the raw material and within hauling distance of a central refinery to which the crude distillate would be shipped for refining, has also been suggested. Any such central refinery would probably be more feasible for the production of pure alcohol than for fuel alcohol because of the higher value of the product, but the central refinery idea is likely to prove uneconomic. Assuming that the capital cost of an alcohol plant is about equally divided into the operation sections of boiler plant, fermenting, distilling, and feed recovery, some duplication of the several sections would occur in a dual plant operation. A boiler installation at the crude plant of sufficient capacity to permit drying of the residual feed (which would have to be done in full at the crude plant as a supplement to the fermentation) could be expanded at nominal expense to the capacity necessary for the refining operation to produce high-test alcohol. At the central refinery there would be a duplication of boiler plant, storage, refining equipment, and labor. The only advantage of the central refinery would be the greater efficiency due to the technical control, which might be extended to supervision of the crude-plant operations, where expert control is greatly needed. A central refinery with large output could afford to maintain a sufficient sales division to market the product, but the necessary extension of sales beyond the local territory would increase the cost, so that no gain over the crude-plant (local sale territory) operation would be secured.

It would appear to be more logical to equip the basic small plants completely with refining equipment adequate to produce a finished fuel-alcohol product. This complete equipment would not entail a serious increase of capital investment over the crude-alcohol requirement. At the same time, however, the size of such a farm plant would have to be determined by the supply of raw material and the demand for the product in the adjacent area; otherwise transportation charges, sales expense, and the more elaborate organization required would increase the cost of the product beyond that of competing industrial alcohol manufactured on a large scale. It would seem that farm plants would necessarily have to be very small.

The so-called small plants, formerly operating on the above system in Germany, generally had a capacity ranging only from 50 to 500 gallons per day, and they operated only on single shifts daily and for only part of the year. Byproduct slop was fed directly to stock in wet form. Table 36 shows the number of plants and annual output of alcohol in the small distillery system in Germany. The system was inefficient (*39*), and the cost of the alcohol produced was high,

although secondary gains from stock raising, crop rotation, etc., might have somewhat offset the distillery losses.

TABLE 36.—*Number of plants and annual output of alcohol in small distillery system in Germany* [1]

Plant		Annual output per plant (gallons)
Kind	Number	
Beverage (brandy)	47,478	Less than 13.
Alcohol	2,054	13 to less than 1,320.
Do	1,571	1,320 to less than 13,200.
Do	1,294	13,200 to less than 26,400.
Do	1,305	26,400 to less than 52,800.
Do	143	52,800 to less than 132,000.

[1] As listed by Kremers (*39*).

This system changed considerably during the World War, with some adaptations of the central refinery idea. Recently, in the larger plants, the trend has been toward the elimination of the central refinery and the installation of refining and anhydrous equipment at each base plant. Most of the cost of producing anhydrous alcohol is incurred in making ordinary 95-percent alcohol, only a relatively small additional cost being required for the equipment and processing to the anhydrous stage.

It is doubtful whether the German scheme could be successfully applied to the United States because of difficulties of regulation, greater geographical areas involved, and other factors. The central-refinery idea, without the small crude plants, amounts merely to the erection of complete alcohol refineries of sufficient size to use all the materials within a short-haul radius in a good producing area and also large enough to make profitable the use of the best equipment as well as the necessary skilled labor and supervision. Such a basis would be more practical. Haulage and sales costs are limitations. Generally expressed, the chief business of the farm is mass production of raw materials and not the manufacture of secondary products from such raw materials, especially manufacture that requires special training or equipment.

SALE AND DISTRIBUTION OF ALCOHOL MOTOR FUEL

An alcohol-fuel industry of sufficient scope to supply an appreciable percentage of the Nation's motor-fuel requirements would create the problem of sale and distribution of the product. It is desirable that all the motor fuel be uniform and interchangeable, at least for a given region. Any uniformity of gasoline fuels existing at present is the result of competition between oil companies, and the situation is not yet stabilized. Present grades of gasoline are roughly comparative on the basis of octane rating or tetraethyl lead content, but the gasoline specifications may vary at different times of the year, even for the same refining company.

The local price is an arbitrary figure which changes without any evident relation to supply or demand or other apparent reason. Use of a factor of fuel behavior, such as the octane rating, makes it possible

to evaluate approximately the various competing gasolines in terms of price. It would seem desirable, therefore, to use a similar system instead of blend percentage in rating alcohol motor fuels.

Competition among motor-fuel retailers is so great that profits are small. Competing stations are located side by side at every point. These stations may be of independent ownership, or partly subsidized or wholly owned by gasoline-producing companies. The present practice of selling several grades of fuel and of maintaining a separate dispensing pump for each adds to the overhead expense. If this complex and heavily taxed system of distribution is confronted with the further competition of a new fuel from a new chain of distributors, the result will probably be serious, and any new fuel that costs more than established fuels will suffer correspondingly, unless its merits justify the higher price.

No separate marketing system for the new fuel should be attempted, but rather all possible economy should be achieved by distributing it through established systems. By this method the cost of distribution of alcohol motor fuels should more nearly approximate that of gasoline. There will then be involved, however, serious questions as to standardization of such motor fuel on the basis of the variations between the gasolines produced by various refiners, as well as problems of competition, unless such motor-fuel blends are carried by all distributors alike. There will be additional cost for installing the extra storage, and a dispensing-pump system will be necessary. If the production and marketing of the alcohol fuel is to be attempted on the basis of a quantity sufficient to have a real effect on petroleum conservation, it may be necessary to revise and standardize all kinds of motor fuel offered for sale.

Distribution of the blend through the channels of the petroleum industry would partly offset the loss due to a 10-percent shrinkage in the manufacture and sale of petroleum products.

CONCLUSIONS

Replacement fuels to supplement future decrease in petroleum production, even if not needed for a decade, should be provided for in advance of any price increase of present fuels.

Future fuels of lowest relative cost will probably be obtained by synthesis from gases and alternatively from agricultural materials.

Blends of ethyl alcohol with gasoline function satisfactorily as fuels for present-type internal-combustion engines, especially with increased engine compression ratios and other favorable changes in design.

The most satisfactory blend for present conditions should contain about 10 percent of alcohol, although other percentages can be used.

Uniformity of concentration and employment of alcohol blends are desirable, and all motor fuels should, therefore, be nationally standardized.

Present crop production is inadequate to permit alcohol production for a national 10-percent blend without encroachment on normal feed, food, and industrial supplies.

Alcohol production from present crop wastes, culls, and surpluses is unlikely to be continuously adequate for a national 5-percent blend. Such materials would provide uncertain annual quantities of alcohol at variable costs.

As present costs of producing alcohol do not permit equal competition between blends and straight gasoline, fuels from agricultural products could be used only with some form of supplementary financial support, which might, however, replace present direct or indirect Government farm aid. Such use of agricultural products would stimulate industrial activity and employment and perhaps increase farm income, but the higher cost of the fuel would ultimately fall on the taxpayer. Although the sale of crop materials unsalable under present conditions would bring farmers a higher gross income, farmers themselves would carry 20 percent or more of the higher cost of alcohol fuels.

Production of motor fuels from agricultural materials would entail economic adjustments and present legal and sociological problems. It would also greatly increase costs of Government administration and control of alcohol, although regulatory difficulties might perhaps be minimized by using an impure grade of alcohol. A suitable denaturant must be found.

Success in perfecting light Diesel engines of mobile character, or engines employing solid or gaseous fuels, or even improvements in present internal-combustion engines not now foreseen would exert a marked influence on future fuel requirements.

SUMMARY

This bulletin presents statistics on the annual production and geographic distribution of various farm crops suitable as raw material for producing alcohol or similar compounds for use in motor-fuel blends. The average fermentable content and anticipated alcohol yields, farm return, relative values, and utilization problems of the crops are discussed. The occurrence of crop surpluses, low or sample grades, and culls is considered. The present alcohol industry is described. Locations and requirements of alcohol production plants, process and equipment problems, and the economic principles involved are discussed. The relative cost and efficiency of various motor fuels are compared. The possibility of producing fuels from materials other than agricultural products is pointed out, and data are given on the national supply of such materials. The manufacture and use of replacement fuels abroad, as well as in the United States, are discussed. Estimates are presented on motor registration, fuel requirements, and percentage of farm-owned vehicles, and the agricultural situation now existing is discussed in relation to the general background thus established.

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